

# Extreme Mapping:

Looking for water on the moon

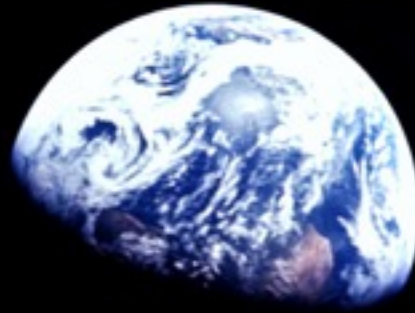
Tamar Cohen

SGT, Inc.

Intelligent Robotics Group

NASA Ames Research Center






What are the exploration challenges we face?

You cannot easily fly surveys over the moon






A photograph of a scientist, Dr. Darlene Lim, in a field setting. She is wearing a grey baseball cap, a light blue t-shirt, and khaki pants. She is kneeling on the ground, which is covered with dark, reddish-brown basaltic rock. She is holding a blue-handled geological hammer and is in the process of sampling the rock. The background shows more of the same rocky terrain.

Scientists prefer to go into the field.  
Dr. Darlene Lim sampling basalt  
Hawaii Volcanoes National Park

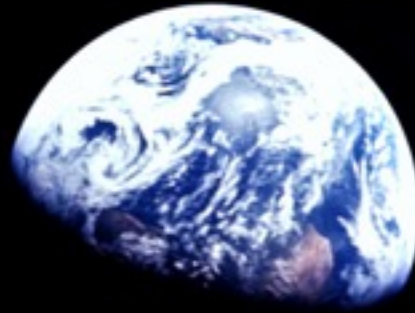
Photo by NASA / Kara Beaton



A black and white photograph of an astronaut on the Moon. The astronaut is wearing a full spacesuit and is using a long-handled tool, possibly a rake or a probe, to interact with the lunar surface. The ground is covered in dust and small rocks, with a distinct shadow cast by the astronaut. The image is overlaid with a grid of white crosshairs.


It is not often we have  
astronauts on Extra-  
Vehicular Activity (EVA)

Apollo 12 astronaut Charles Conrad Jr.



Why should we look for water on the moon?



A photograph of an astronaut with curly hair, wearing a dark blue flight suit with "FIVE EAGLES" embroidered on the sleeve, looking out of a large circular window of a space station. The Earth's blue surface and white clouds are visible through the window. The interior of the station is dark with various equipment and structural elements visible.

Human space exploration  
People need to drink almost 2  
liters of water per day

NASA Photo / Tracy Caldwell Dyson

Today it costs \$450 to  
launch one kg.

Photo: Pat Corkery  
United Launch Alliance





Yes, we recycle urine on the ISS  
Water Recovery System



We can use water to make fuel.



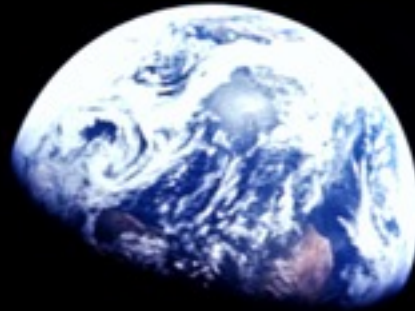
Apollo 11 lunar module returning from the moon.



Finding water ice on the moon helps us learn about the moon's history.



Image: NASA / JPL - Caltech



What do we already know?



## Moon facts:

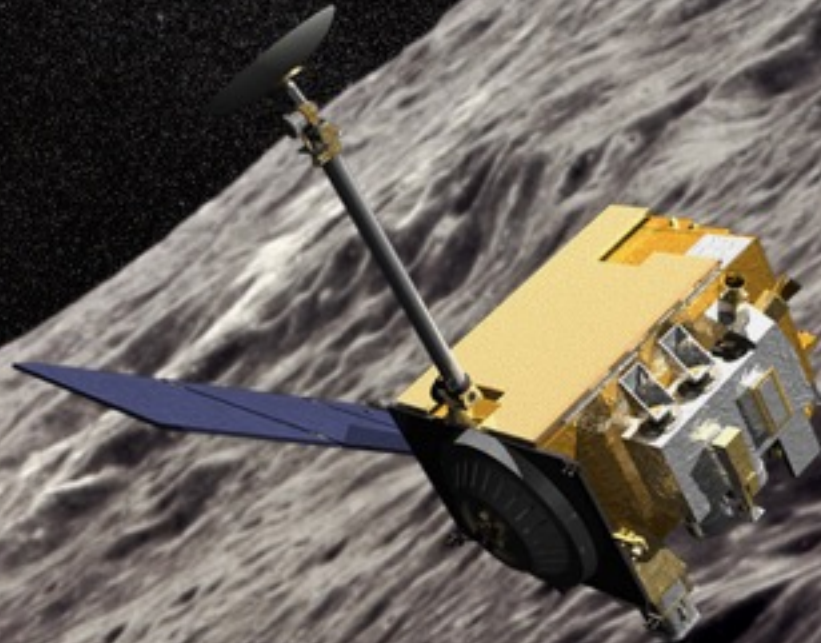
384,400 km (238,900 mi)  
from Earth

Temperatures from  
123 °C (253 °F) to  
-233 °C (-387 °F)

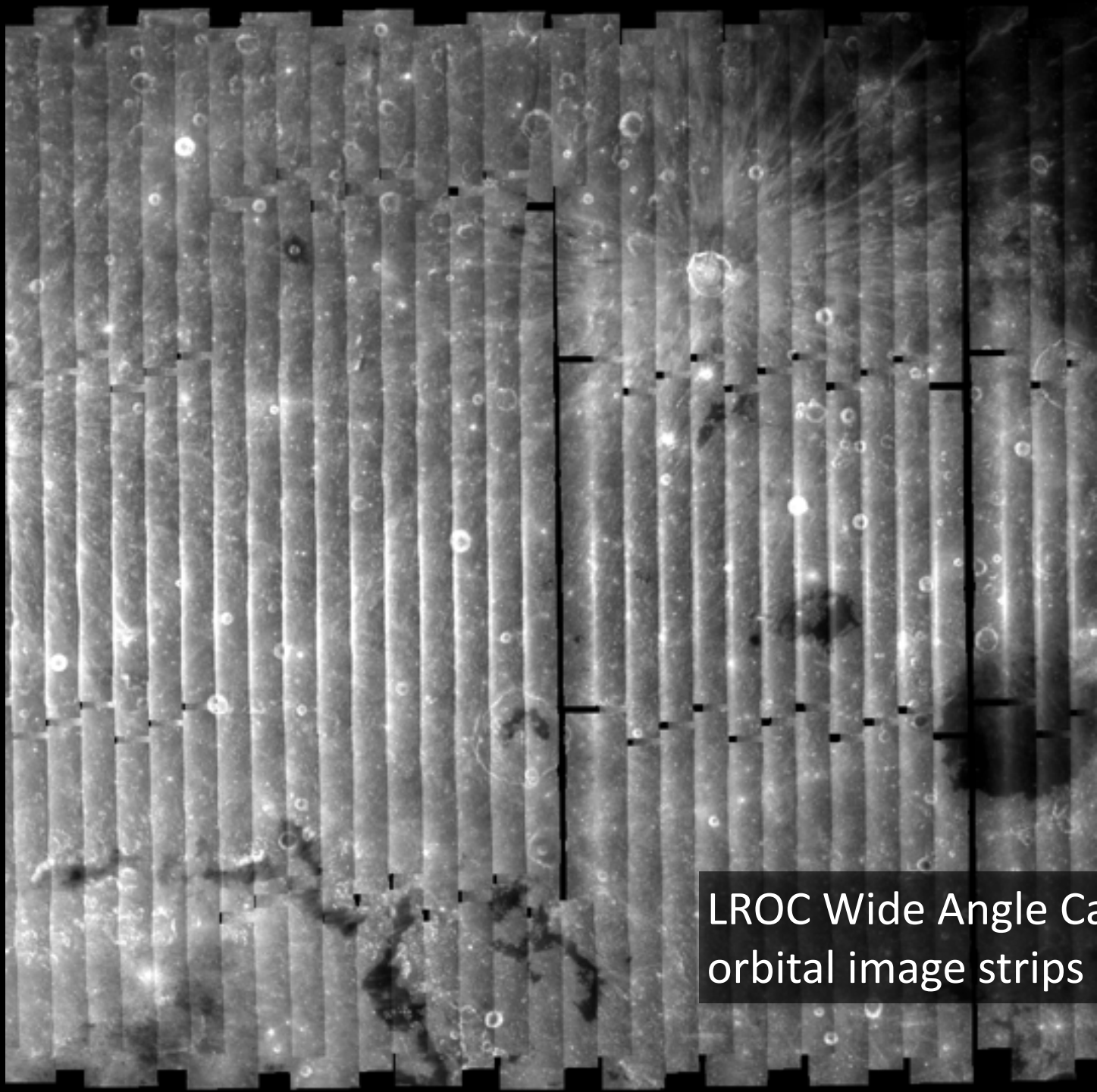
The same side of the moon is  
always facing the earth.



Lunar Reconnaissance Orbiter (LRO)  
gathers high resolution maps and data

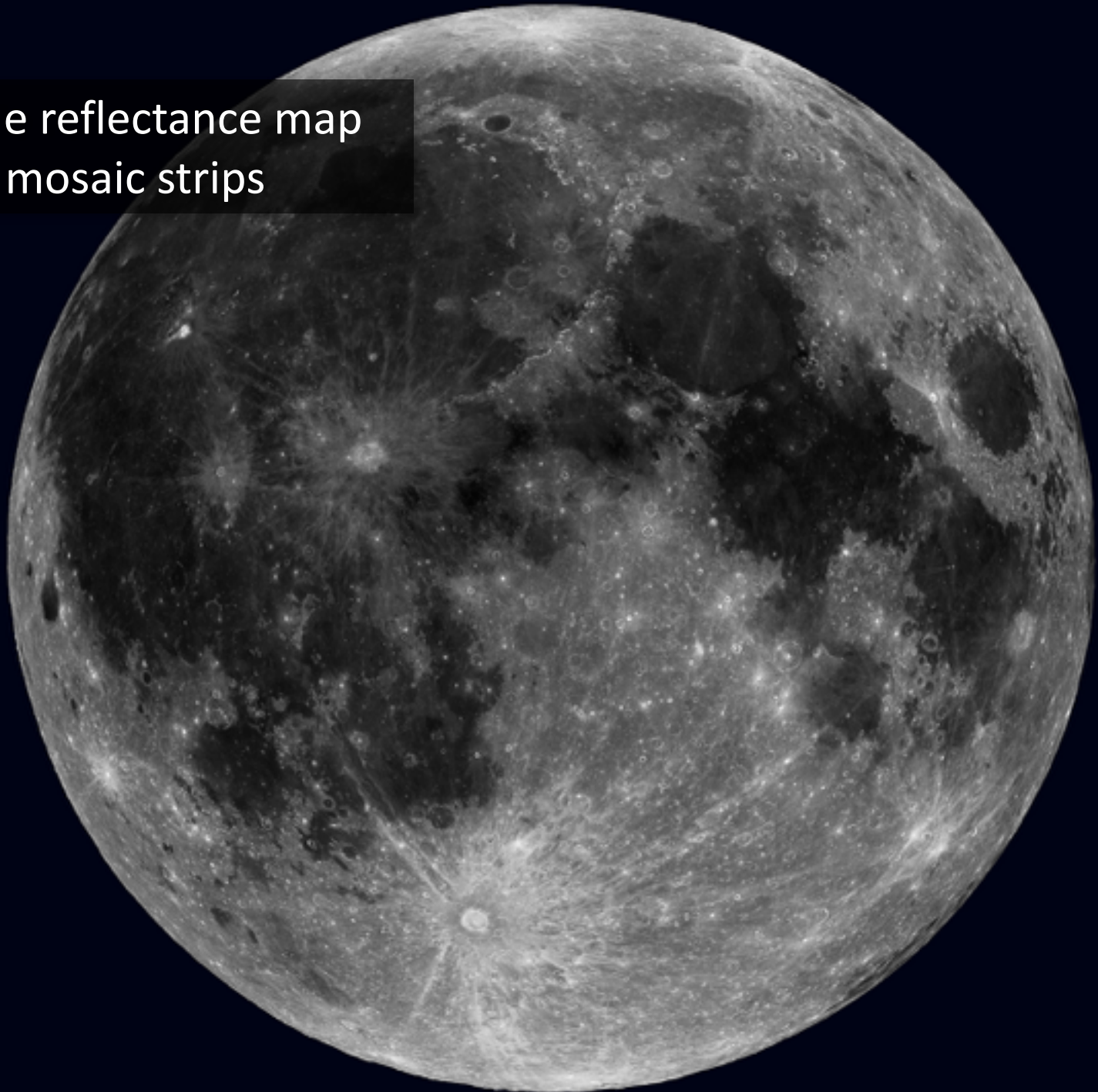






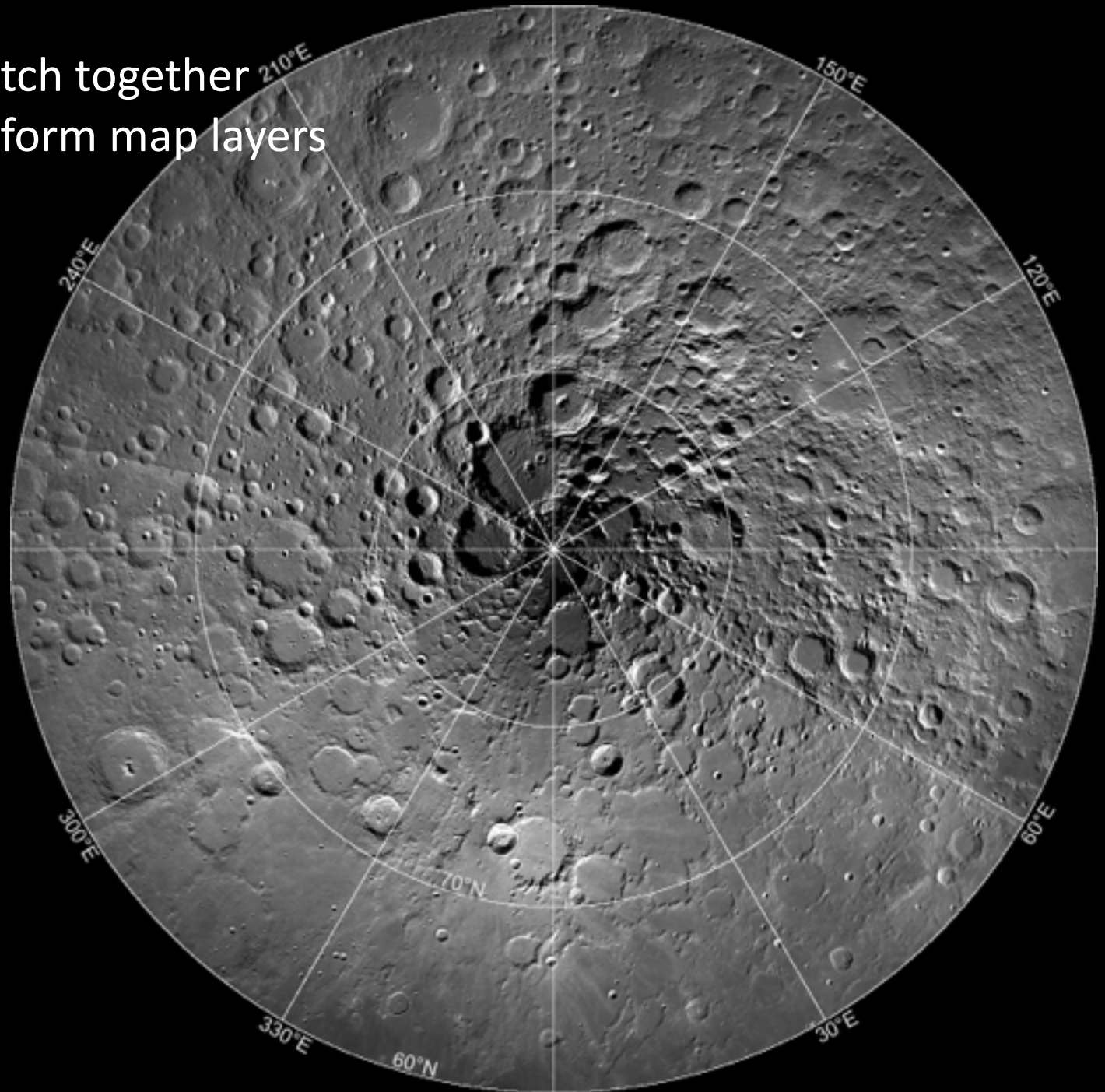
LROC Wide Angle Camera  
orbital image strips

Nearside reflectance map  
built of mosaic strips

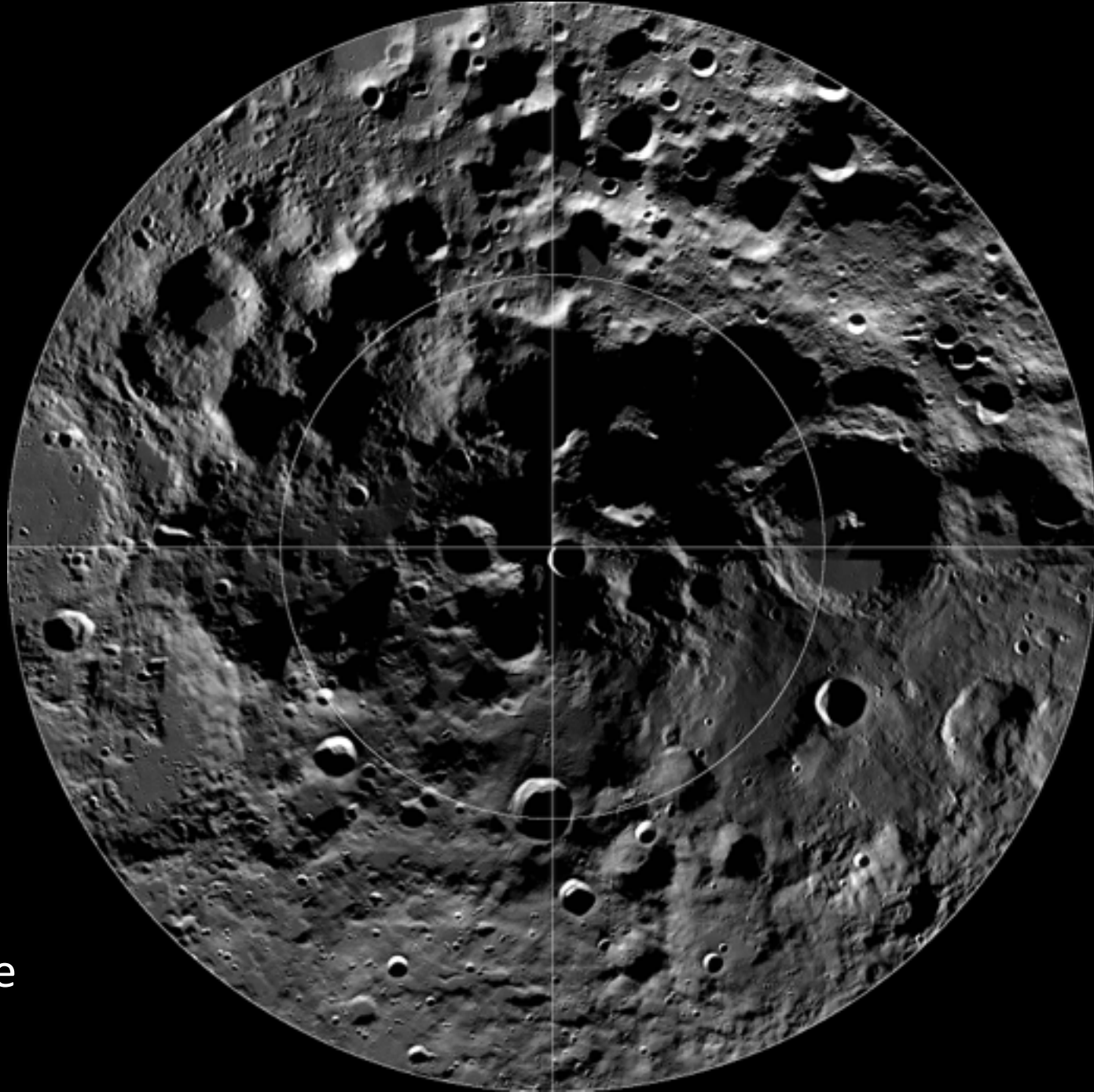




We can stitch together  
images to form map layers



Lunar  
North Pole



Lunar  
South Pole



# Lunar Reconnaissance Orbiter Camera

[Home](#)[About](#)[Images](#)[Archive](#)[Learn](#)[Teach](#)[WMS Browser](#)[Thumbnail Browser](#)[Image Search](#)[Overview](#)[Layers](#)

## Map Options

Cursor Latitude: 85.696  
Cursor Longitude: -97.976

Projection: North pole stereographic

### Single-click action

- ☒ None (double-click to zoom)
- ☐ Recenter
- ☐ Recenter & Zoom
- ☐ Get Footprint Info

[Permalink](#)

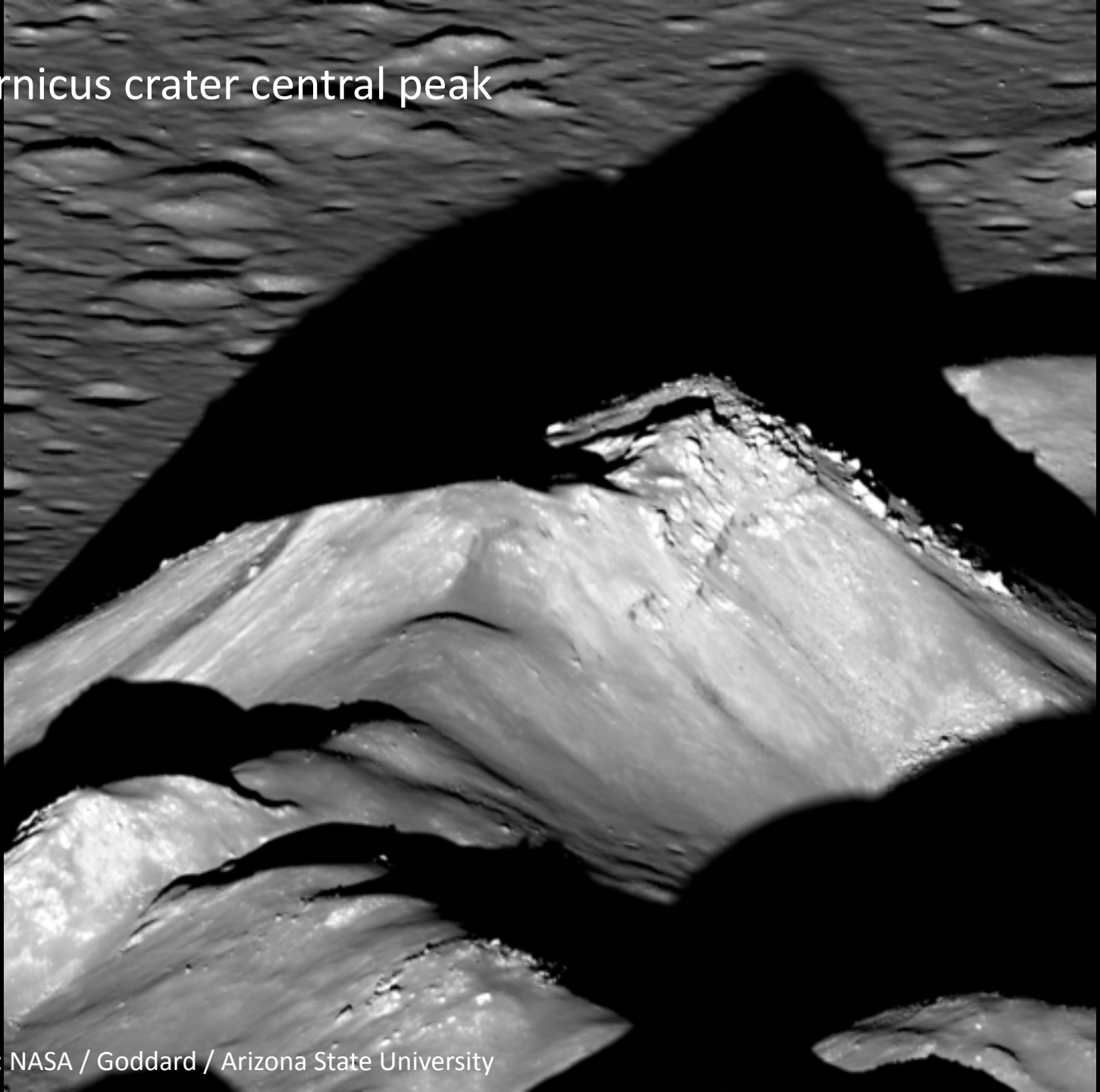
692.65km (at projection center)

Arizona State University  
<http://wms.lroc.asu.edu/lroc/>

# Floor and eastern wall of Antoniadi crater

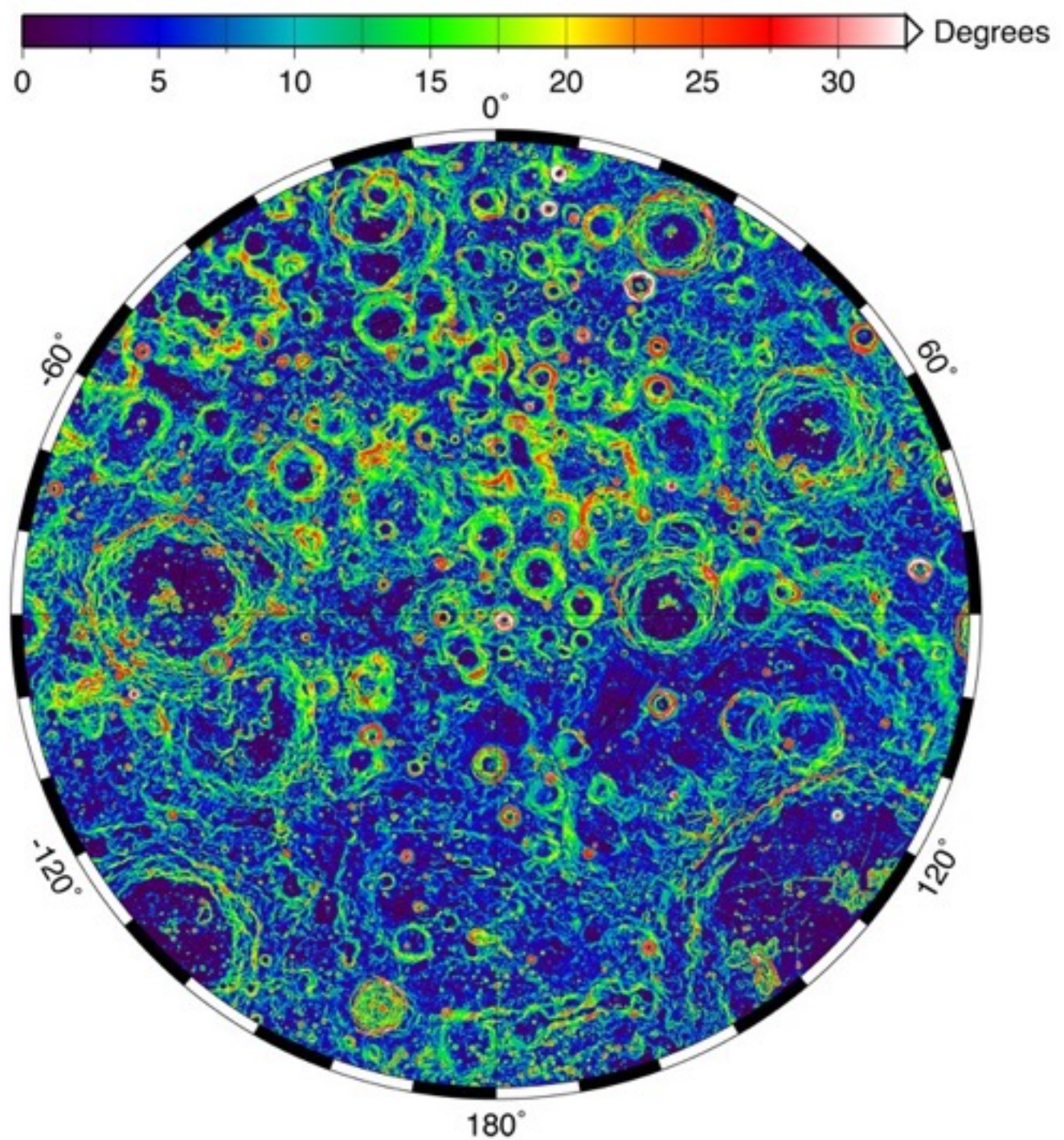


# Copernicus crater central peak

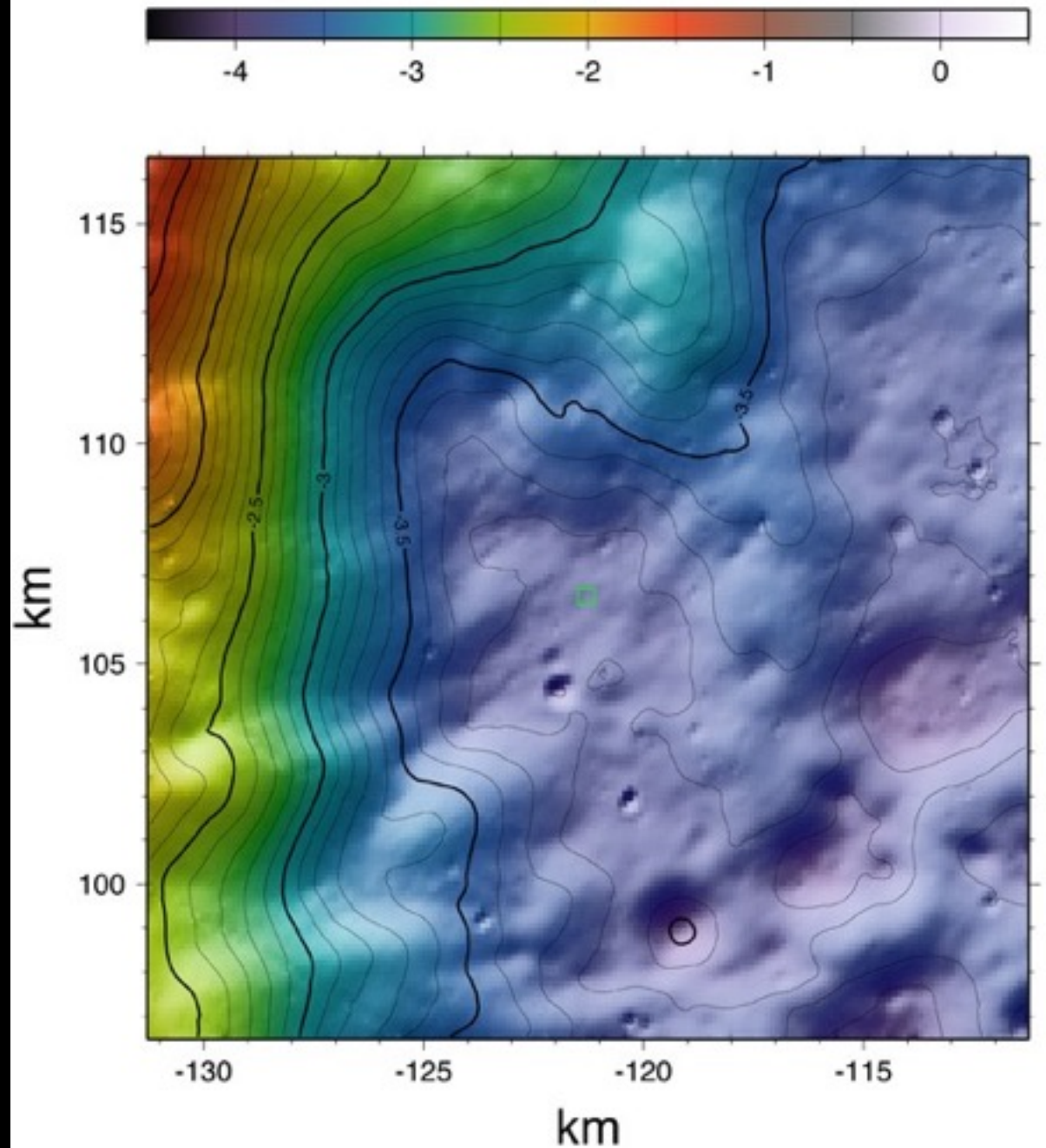




# Slope map from LOLA



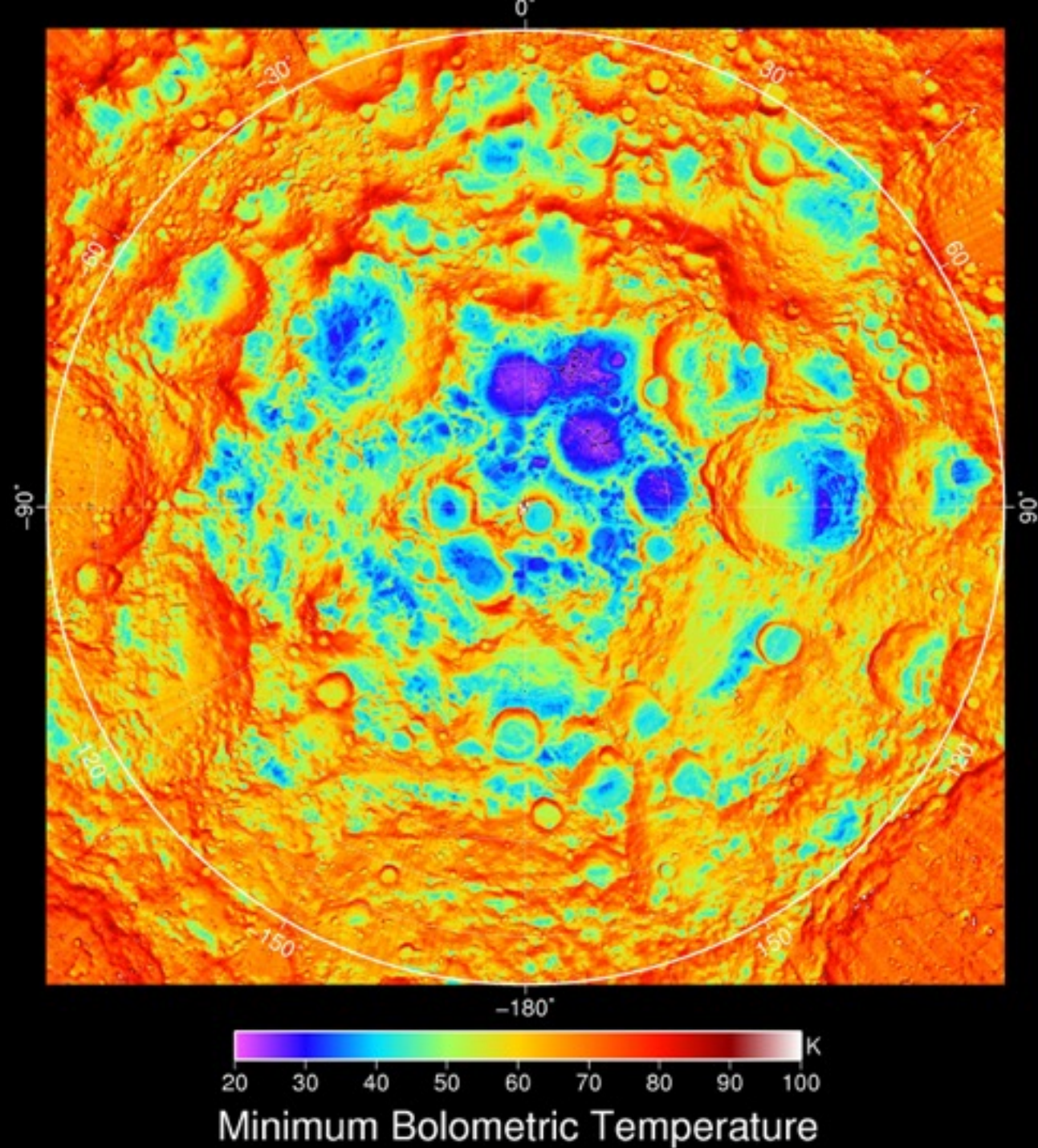
LRO's LOLA  
measures topography  
using lasers



LOLA topography of LCROSS landing

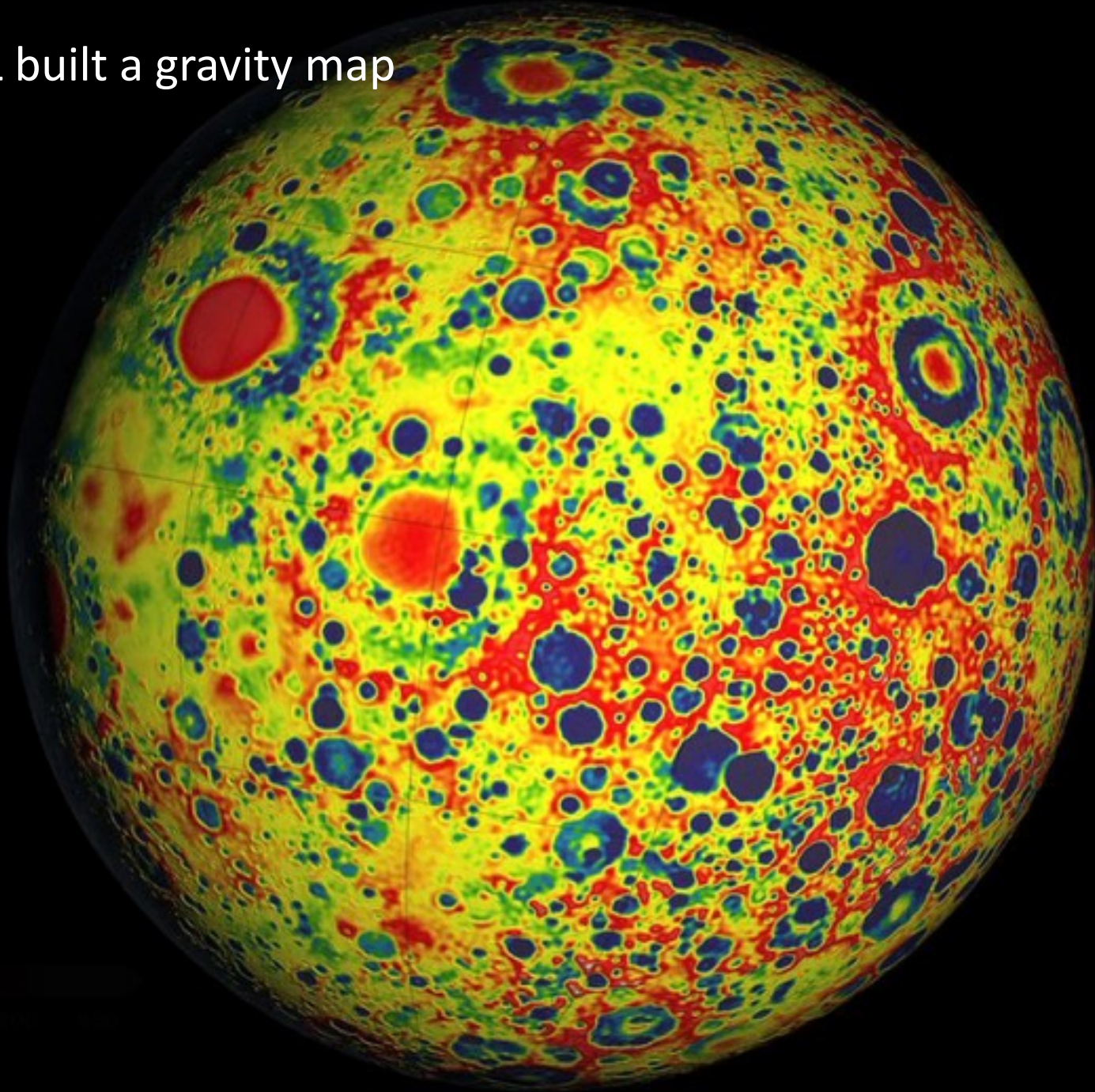


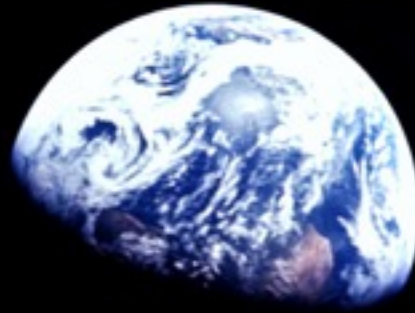
LRO's DIVINER  
measures surface  
temperature





GRAIL built a gravity map





We know that there is water ice on the moon.



Lunar Crater Observation  
and Sensing Satellite  
(LCROSS)  
measured hydrogen on  
the moon





# Simulation of LCROSS deployment



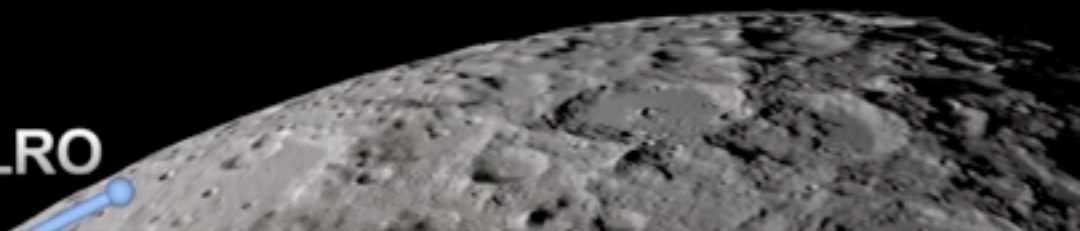
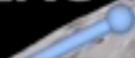
LCROSS plume



LCROSS



LRO





What is the proposed Resource Prospector Mission?

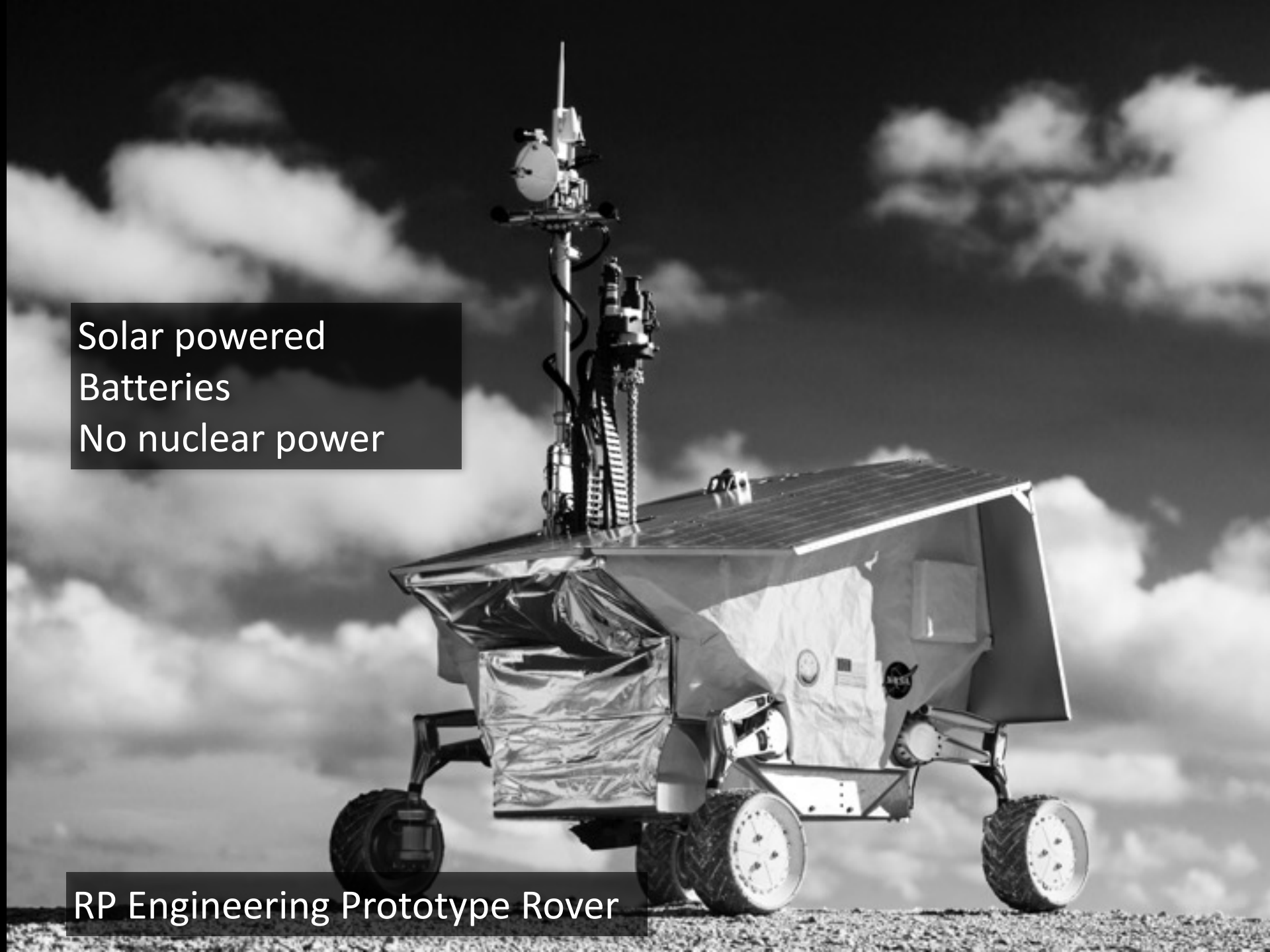






# RP Engineering Prototype Rover



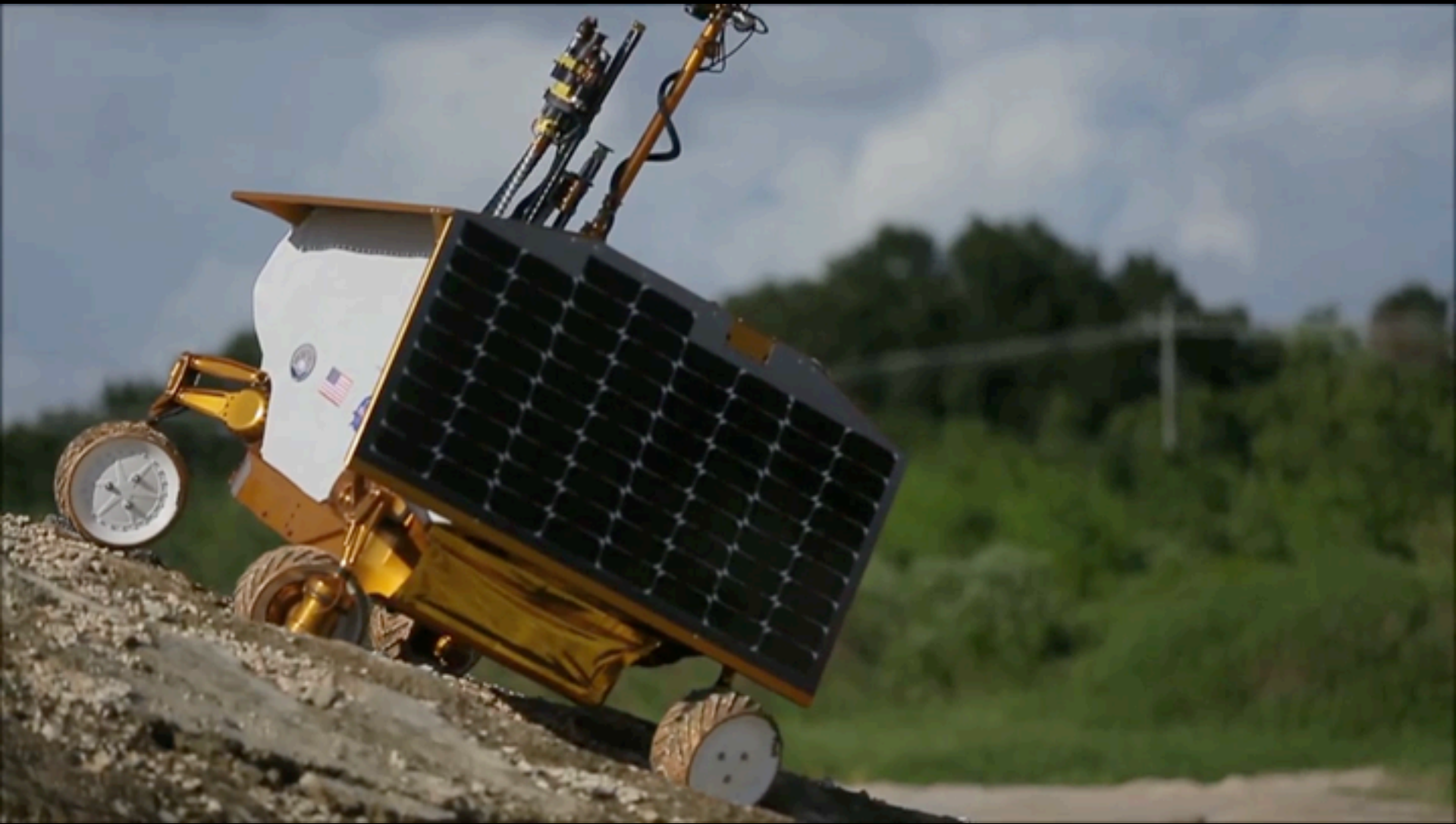
A black and white photograph of a four-wheeled rover prototype on a rocky surface under a cloudy sky. The rover has a boxy body with a solar panel on top and a tall mast with various instruments. The text 'Solar powered', 'Batteries', and 'No nuclear power' is overlaid in a dark box on the left. The text 'RP Engineering Prototype Rover' is overlaid in a dark box at the bottom left.

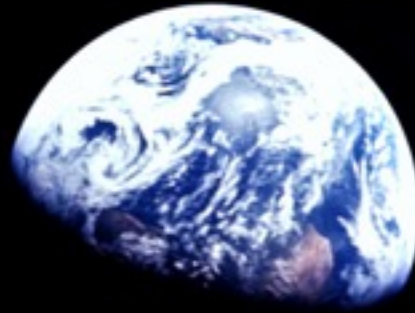
Solar powered  
Batteries  
No nuclear power

RP Engineering Prototype Rover



# RP Engineering Prototype Rover in action





How do the instruments work to detect water?

# Near Infrared Volatile Spectrometer System NIRVSS

Hydrogen spectrum



Detects surface elements



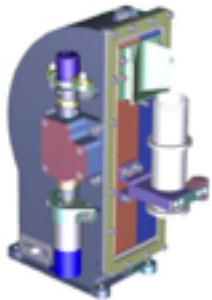
# Neutron Spectrometer System NSS



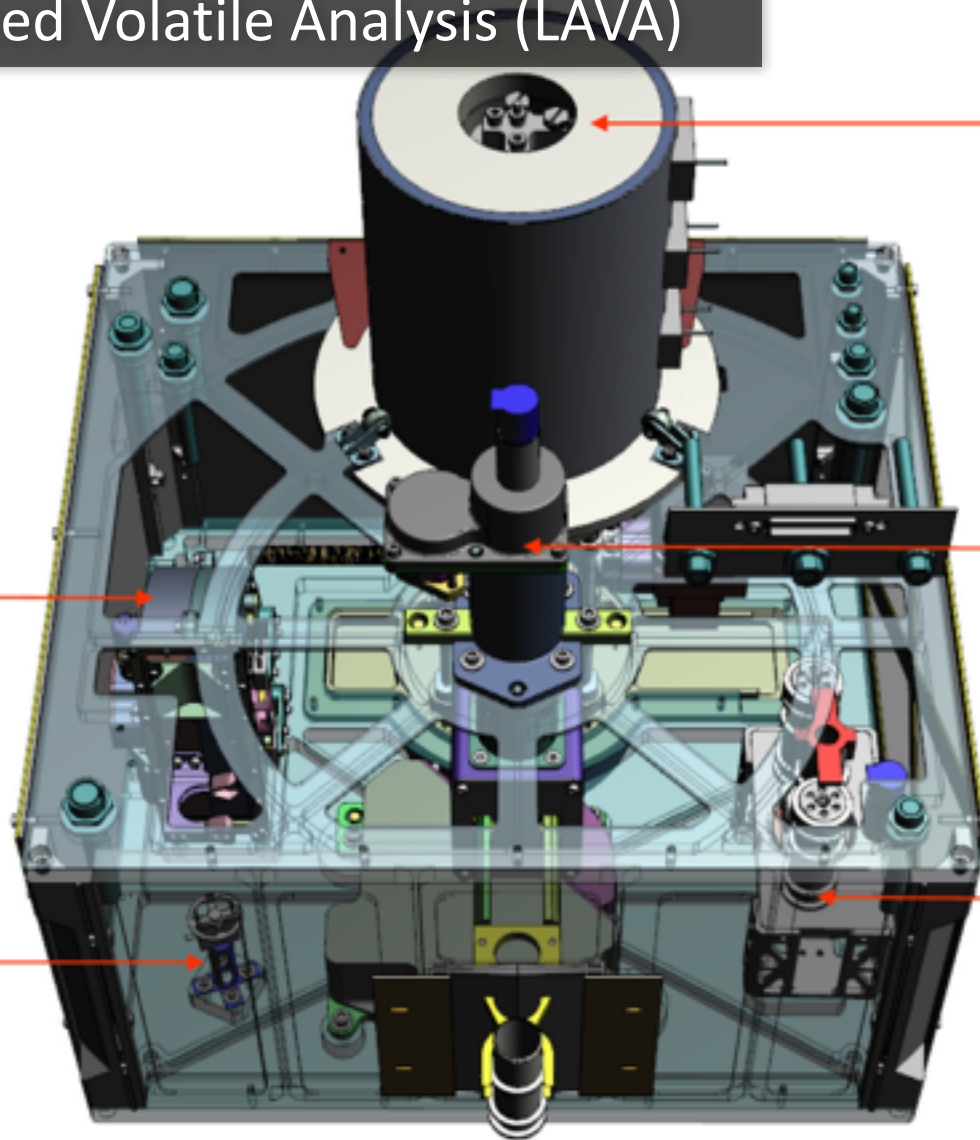
Detects subsurface elements

# Oxygen and Volatile Extraction Node (OVEN) & Lunar Advanced Volatile Analysis (LAVA)

**REMOVAL STATION**  
Discards Regolith Samples



**WEIGH STATION**  
Weighs Regolith Samples



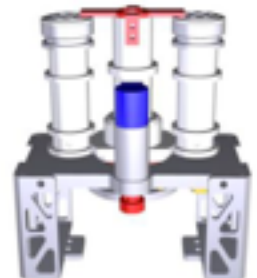
**REACTOR STATION**  
Elevates/Seals/Heats  
Regolith Samples



**ARM**  
Rotates/Elevates/Extends  
Crucibles



**STORAGE STATION**  
Stores 2 Crucibles



**REGOLITH SAMPLE INLET**  
Drill Interface



# RP Engineering Prototype Rover

**Subsurface Sample Collection**  
Drill

**Operation Control**  
Flight Avionics

**Resource Localization**  
Neutron Spectrometer  
System (NSS)

**Sample Evaluation**  
Near Infrared Volatiles  
Spectrometer System (NIRVSS)

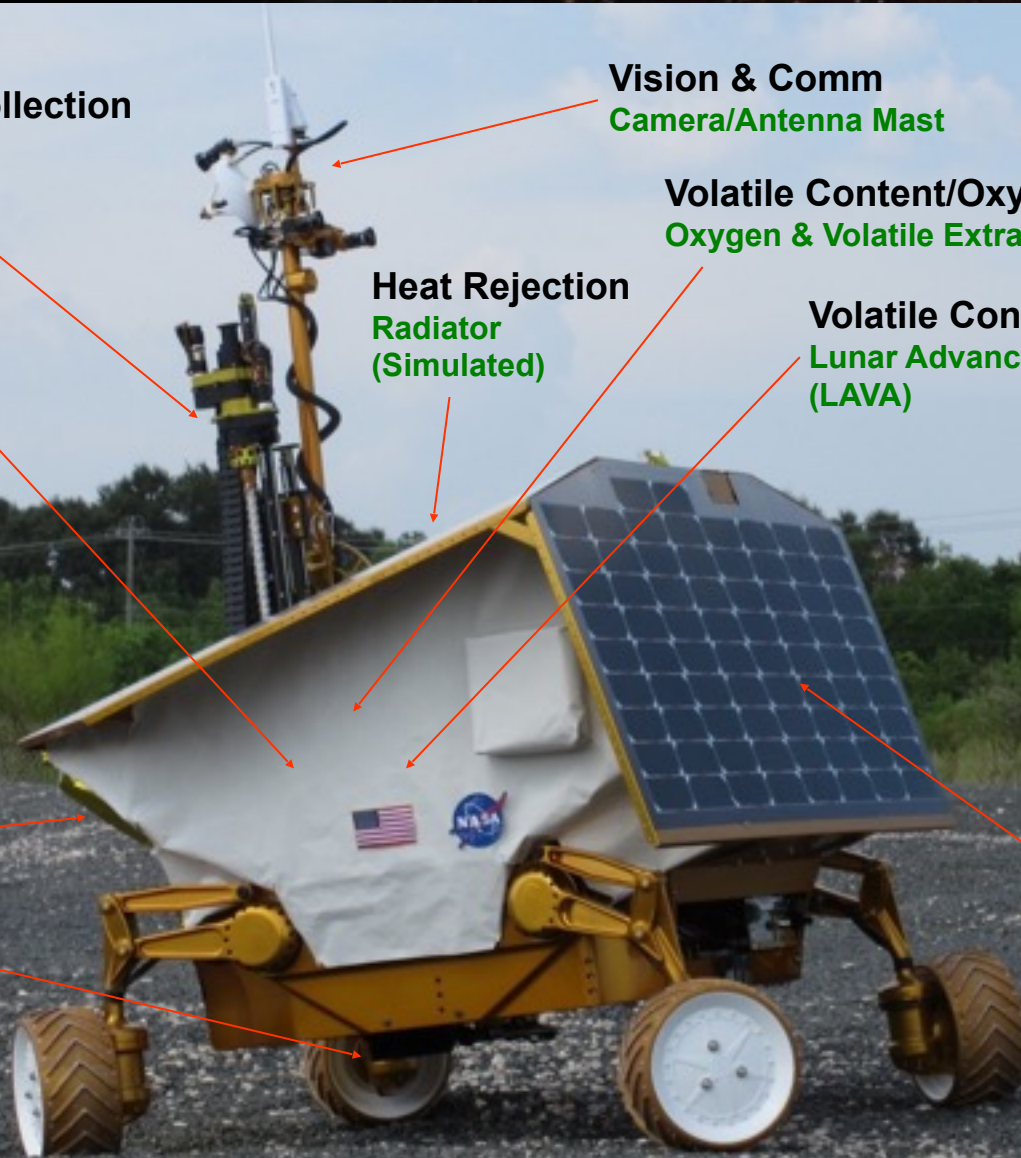
**Vision & Comm**  
Camera/Antenna Mast

**Heat Rejection**  
Radiator  
(Simulated)

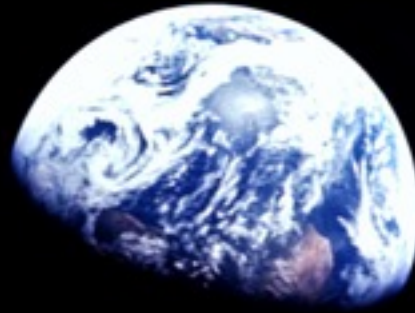
**Volatile Content/Oxygen Extraction**  
Oxygen & Volatile Extraction Node (OVEN)

**Volatile Content Evaluation**  
Lunar Advanced Volatile Analysis  
(LAVA)

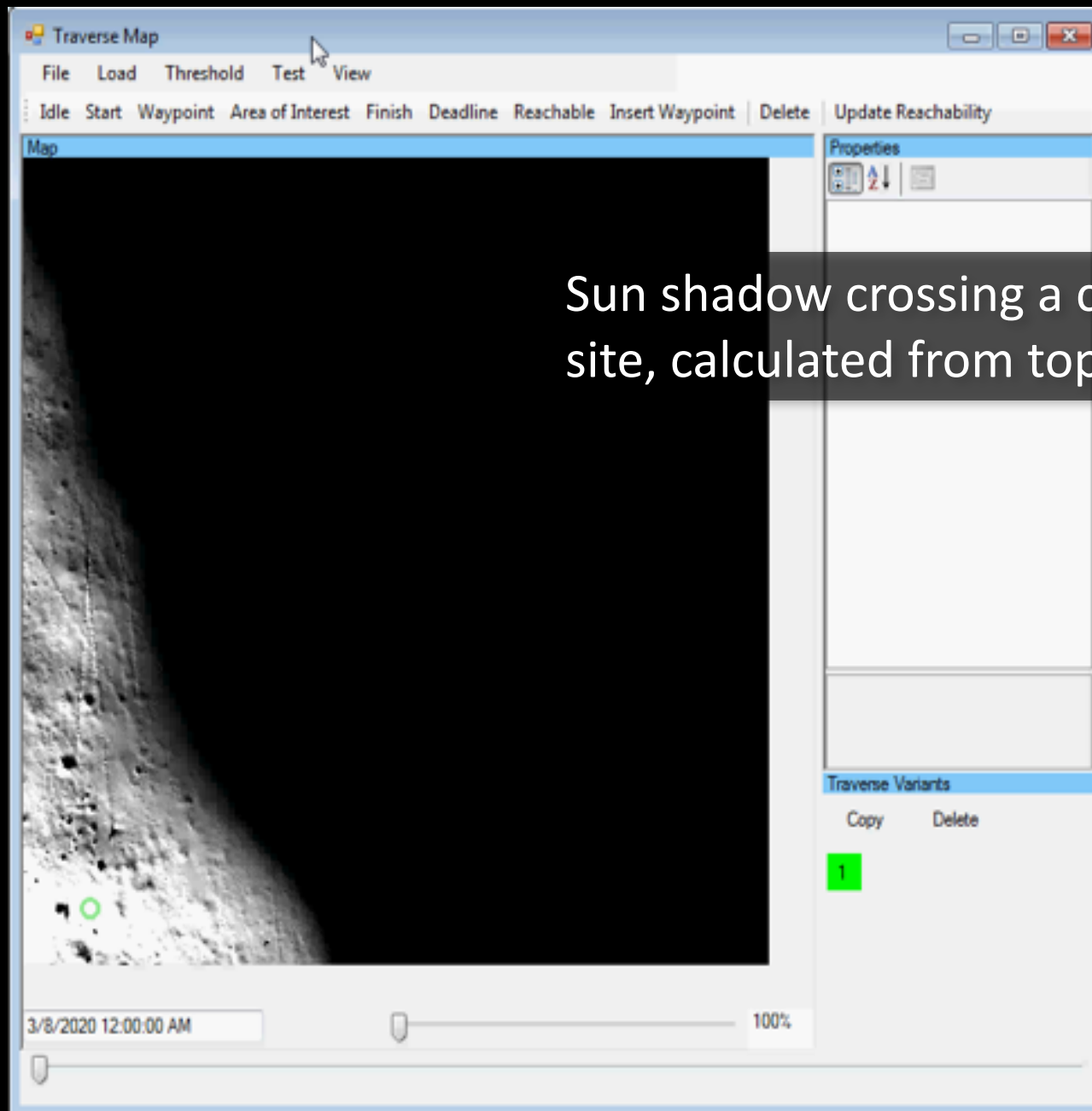
**Power**  
Solar Array  
(Simulaed)





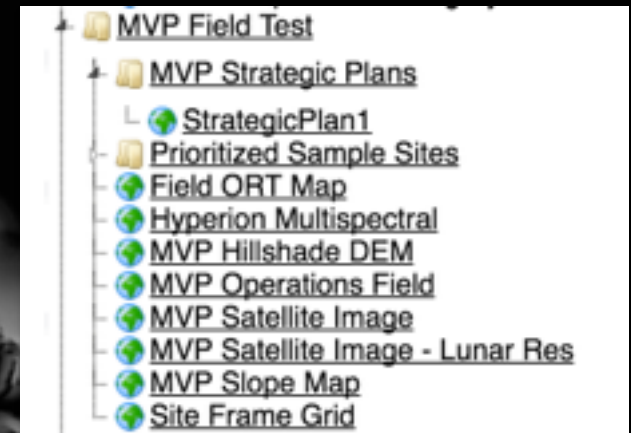


How do we plan where to send the rover?



Sun shadow crossing a candidate site, calculated from topography

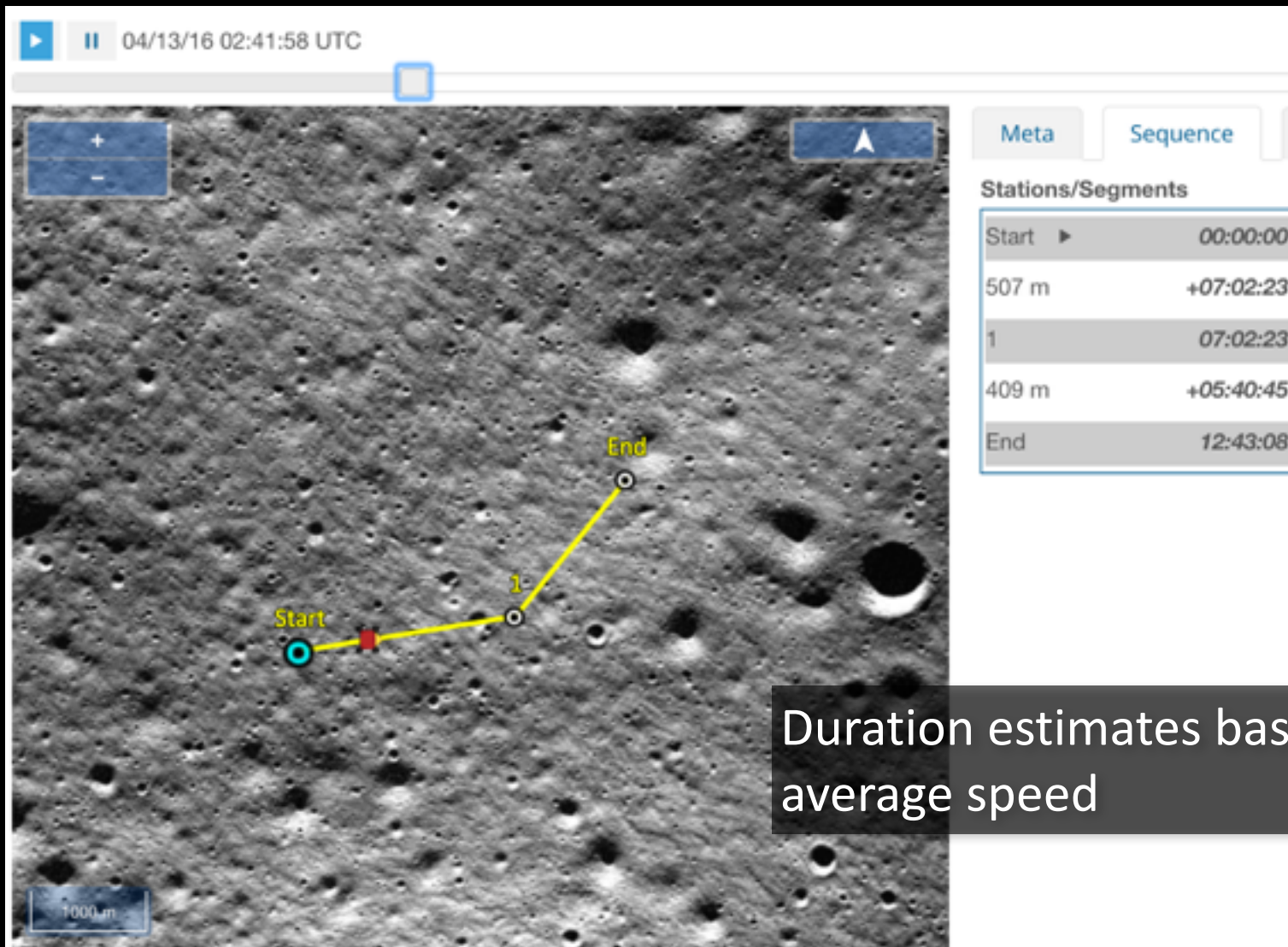
## Build map layers and mark up maps



Multi-temporal illumination map of  
the lunar south pole



# Create simple sequential route plans in xGDS on OpenLayers 3 (Exploration Ground Data Systems)



# How much time does the rover have left in each area?

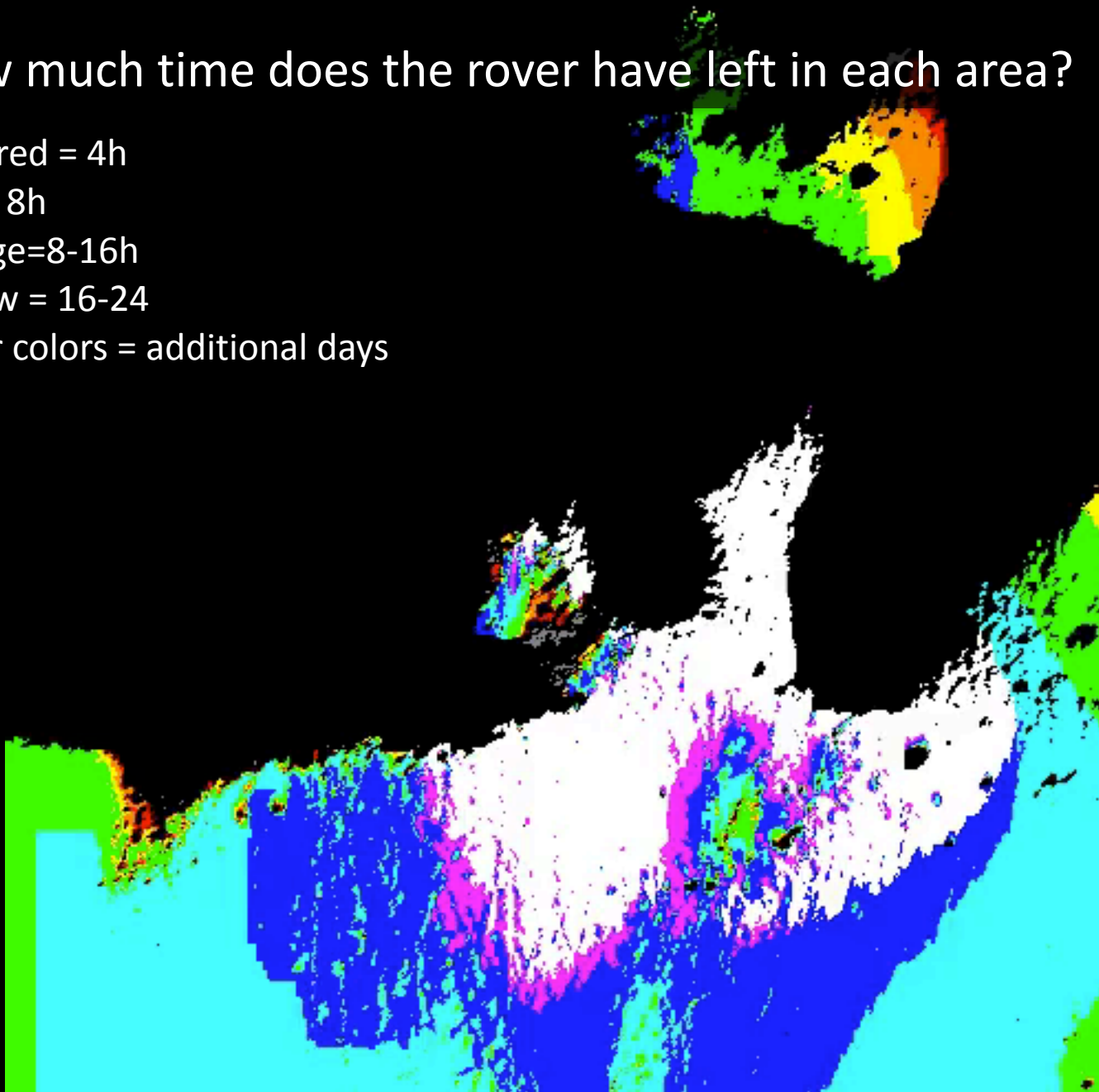
dark red = 4h

red = 8h

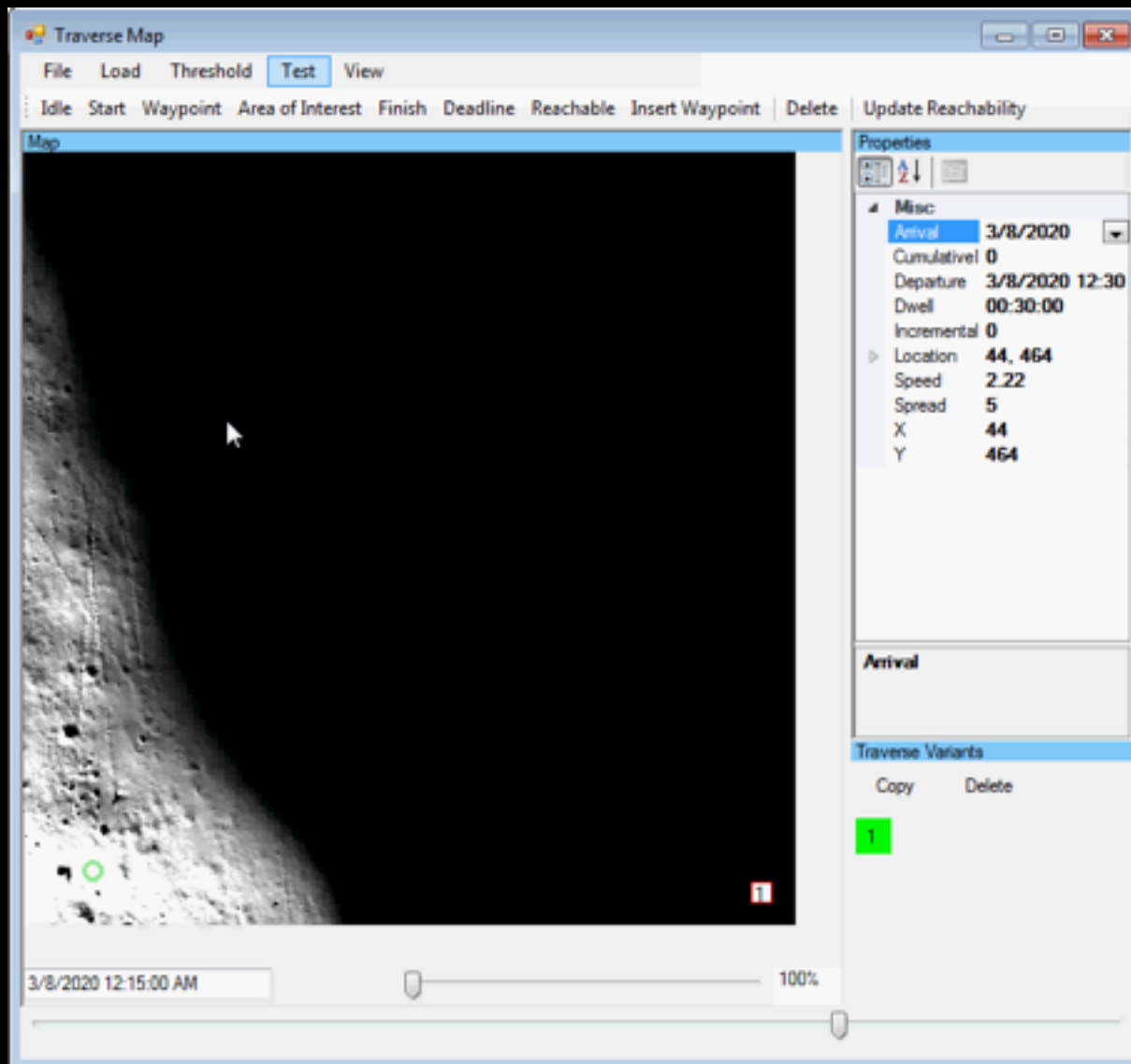
orange=8-16h

yellow = 16-24

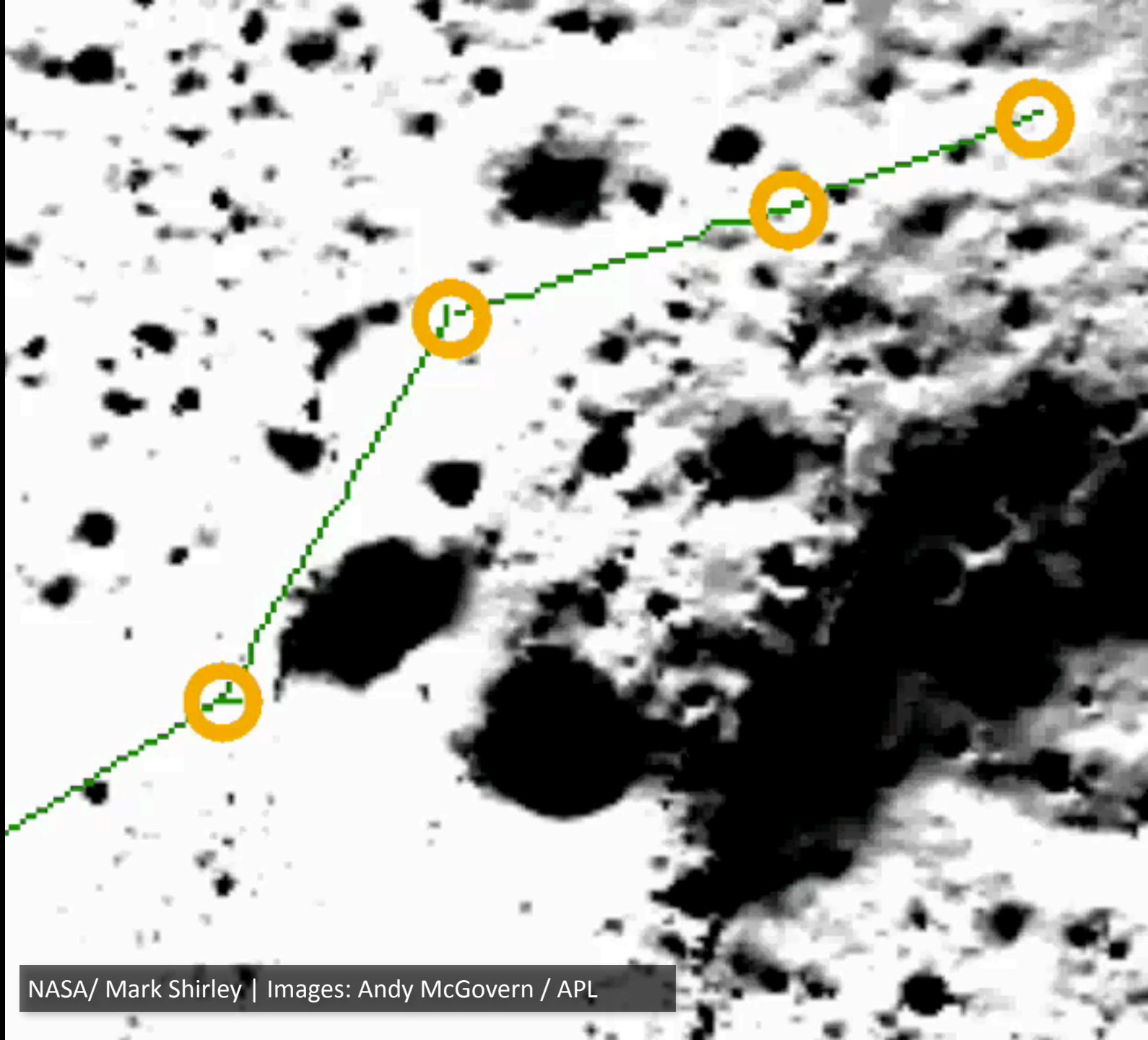
other colors = additional days



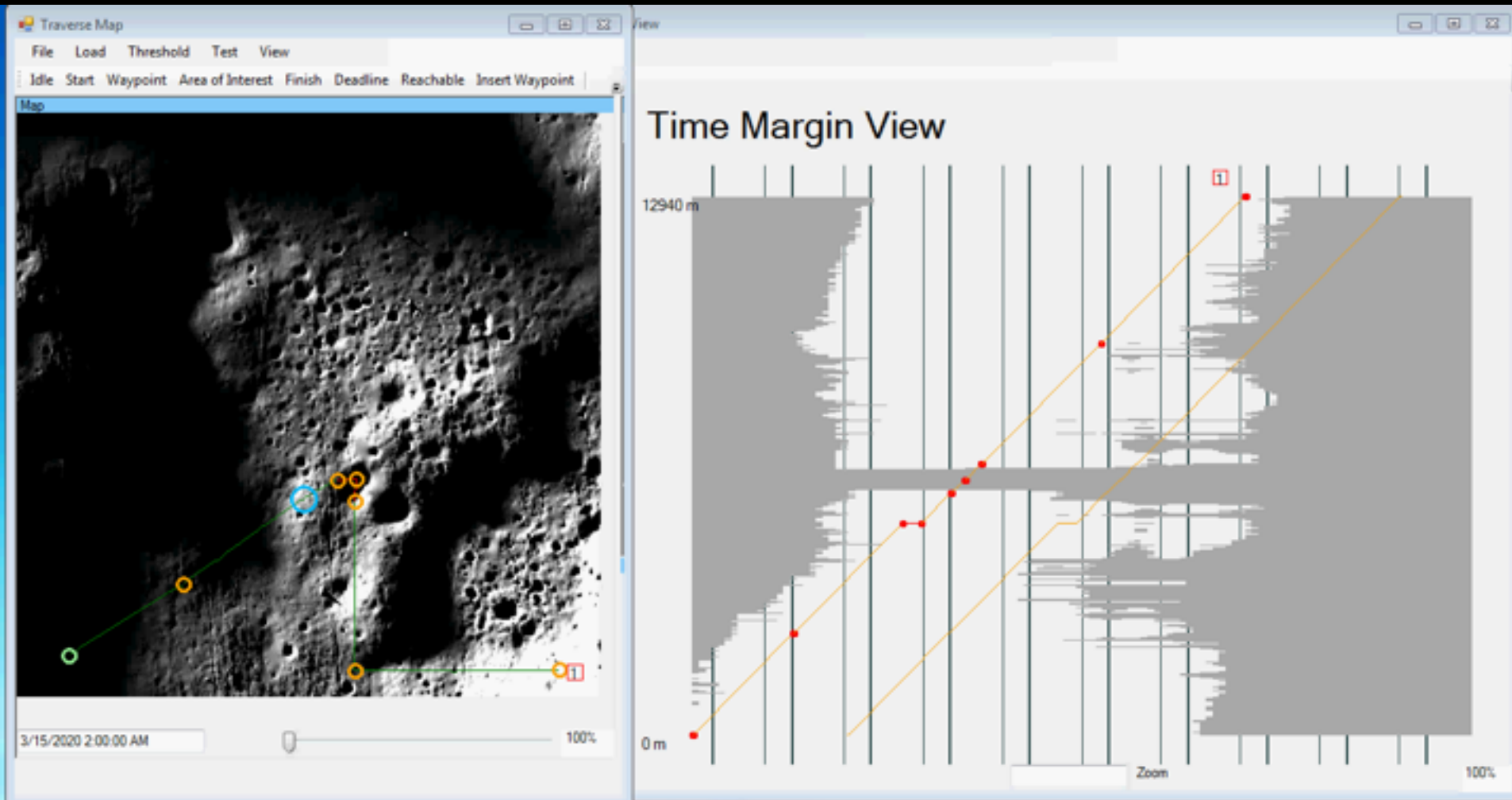
# Prototype planner: can the rover follow the proposed route?







# Prototype planner: How much margin is there at each point?





How do we communicate with a rover on the moon?

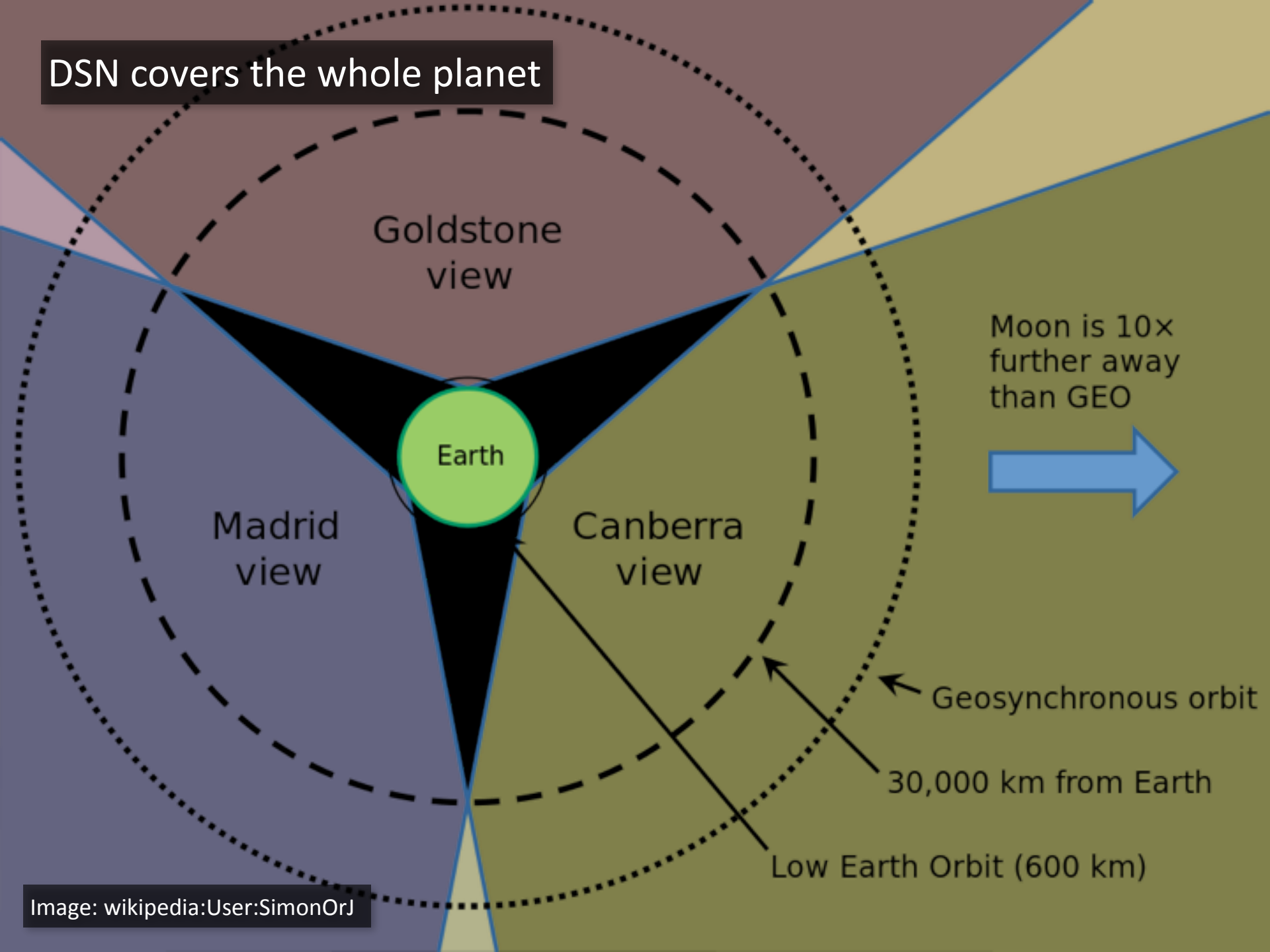


We communicate with the  
Deep Space Network (DSN)

Goldstone Antenna



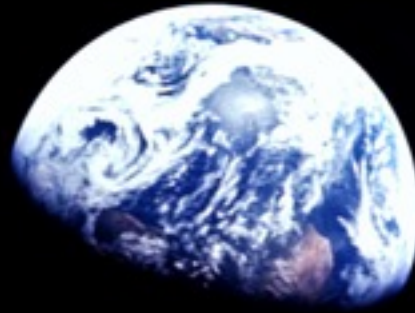
DSN covers the whole planet



It can take 2 minutes to  
communicate one way  
between the Earth and the  
Moon over the DSN.

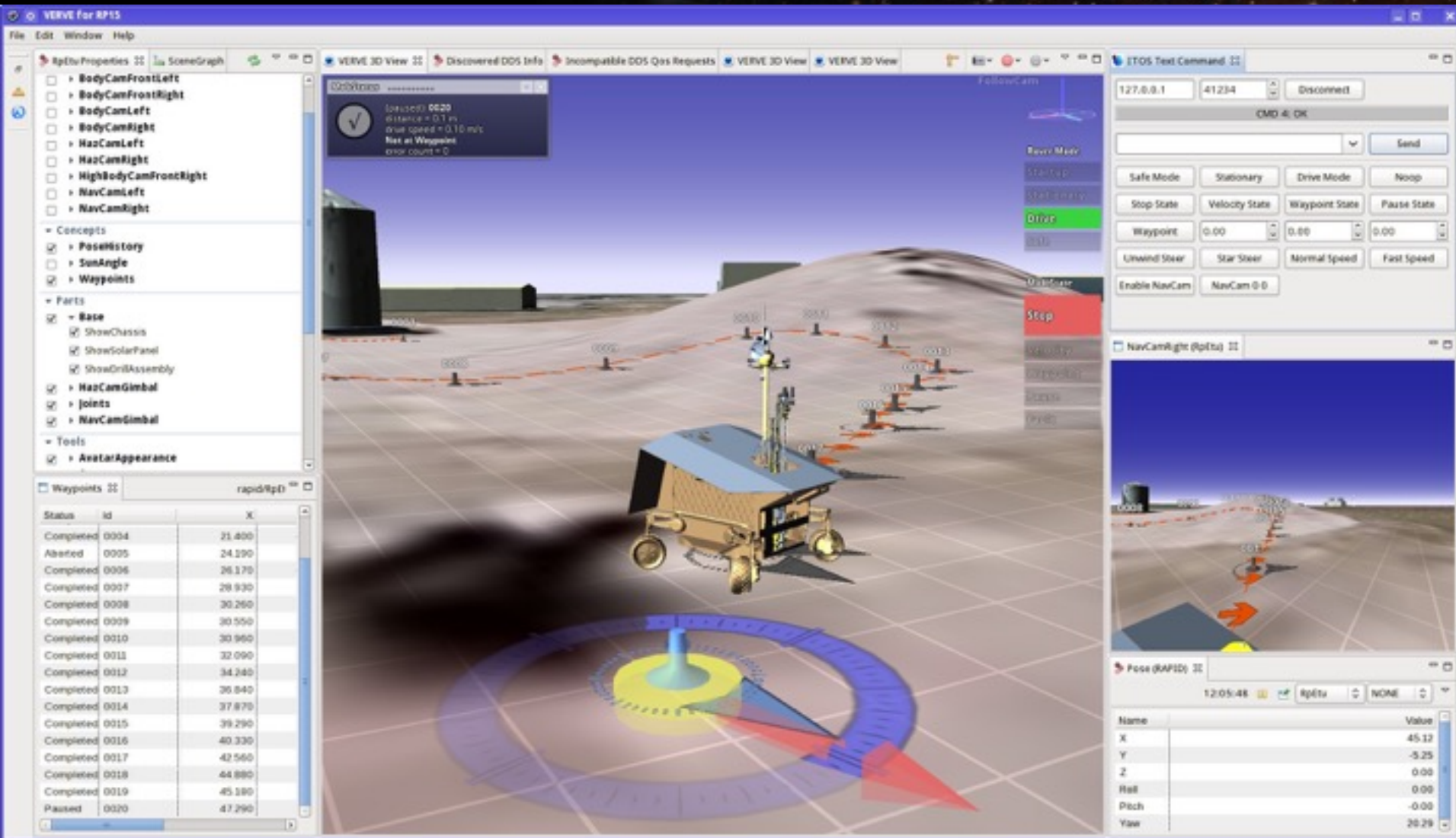






How do we remotely operate a rover on the moon?

# Rover Operator Interface (VERVE)



# In VERVE, we customize tabular views to show diagnostics

The screenshot displays the VERVE software interface, which is used for simulating and controlling a rover. The central 3D view shows a rover on a grey, textured surface with a pink and blue terrain map overlaid. A green path with arrows indicates the rover's trajectory. A distance of 11.4m is shown between two points on the path. A small window titled 'Macros on Pending Queue' is visible in the top left of the 3D view.

On the left side, there are several panels:

- Plan Manager:** A table showing plans on the rover and on the local file system.
- Run Plan:** A panel for running a specific plan, showing details like Name, ID, Version, and Description.
- Command Log:** A table showing a list of commands and their durations.

On the right side, there are several panels:

- Access Control View:** A panel for controlling the rover, showing buttons for Request Control, Release Control, and Grab Control.
- ImageSens:** A panel showing the current image from the rover's camera.
- Process Manager:** A panel showing the status of various processes.
- Log Monitor:** A panel showing the log output of the rover.
- GPS (RAPID):** A panel showing the GPS data.
- Robot Subsystems (RAPID):** A panel showing the status of the robot's subsystems.

Name	ID	Version	Duration
CheckOut Basic	MVP2184_B_PLAN	B	00:00:30
MVP_2184_C_P18_A30C	MVP2184_C_PLAN	C	01:09:34
MVP_2184_C_P18_A30C	MVP2184_C_PLAN	D	01:09:34

Name	ID	Version	Duration
MVP_2184_C_P18_A30C	MVP2184_C_PLAN	C	01:09:32

Name	ID	Version	Description
MVP_2184_C_P18_A30C	MVP2184_C_PLAN	C	

Duration	Command	ID
00:01:00	Drive	MVP2184_C_SEG13_8_NAV
00:00:00	SetSpeed	MVP2184_C_SEG14_8_NAV17
00:02:45	Drive	MVP2184_C_SEG14_8_NAV
00:00:00	SetSpeed	MVP2184_C_SEG15_8_NAV18
00:02:57	Drive	MVP2184_C_SEG15_8_NAV
00:00:00	SetSpeed	MVP2184_C_SEG16_8_NAV19
00:02:43	Drive	MVP2184_C_SEG16_8_NAV
00:00:00	SetSpeed	MVP2184_C_SEG17_8_NAV20
00:02:27	Drive	MVP2184_C_SEG17_8_NAV
00:00:00	SetSpeed	MVP2184_C_SEG18_8_NAV21
00:02:26	Drive	MVP2184_C_SEG18_8_NAV
00:00:00	SetSpeed	MVP2184_C_SEG19_8_NAV22

State	Name
Running	KRex2_Controller
Running	KRex2_RTLogRecorder
Running	GroundCam_Image_Compressor

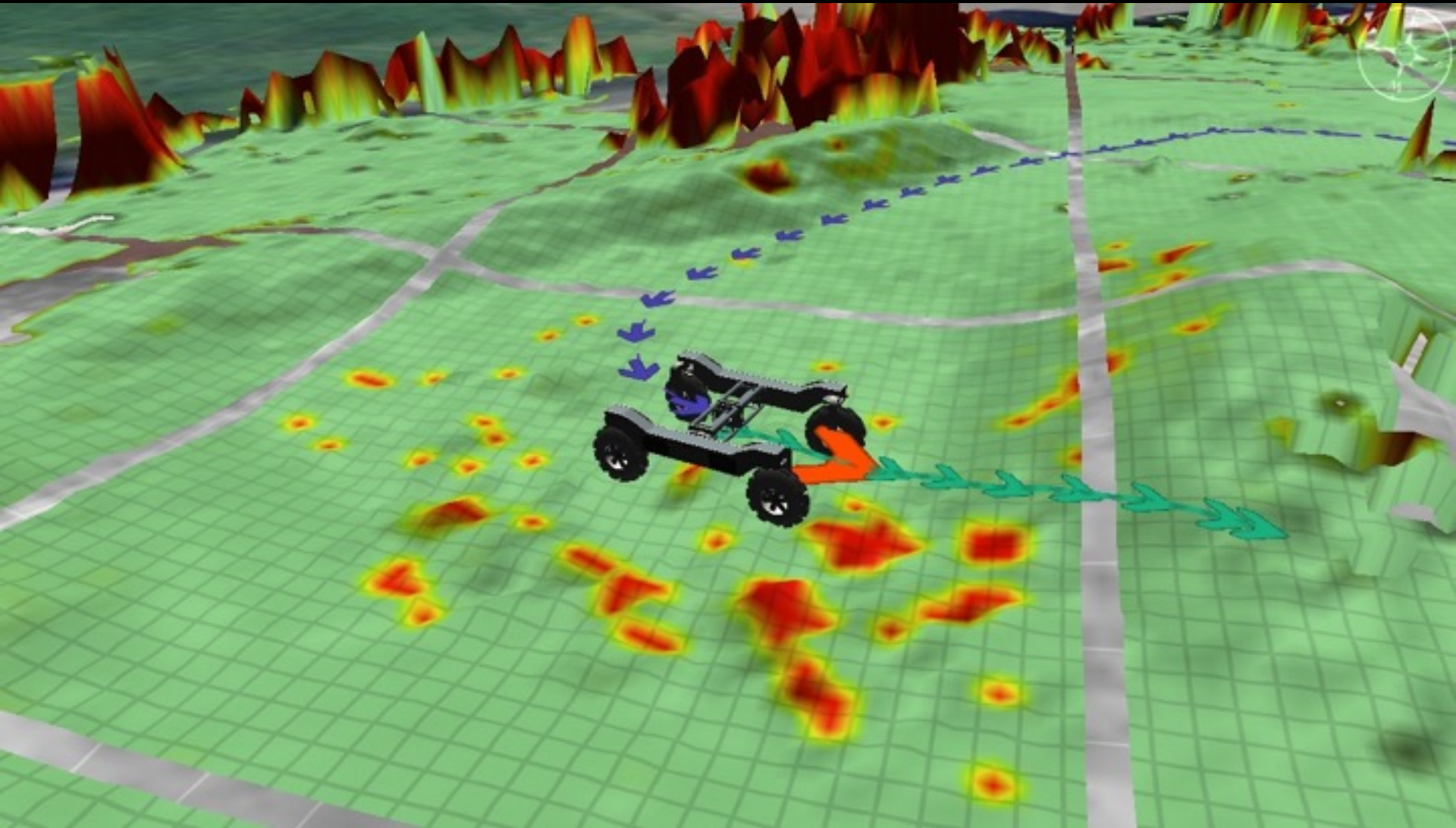
Name	Value
X	30.28
Y	-11.09
Z	3.40
Roll	-1.43
Pitch	4.37
Yaw	-129.82

Name	Value
Latitude	1.288558
Longitude	104.000000
Altitude	2.824729
Speed	0.000000

Name	Value
Temperature	20.00
Pressure	1013.25
Humidity	65.00

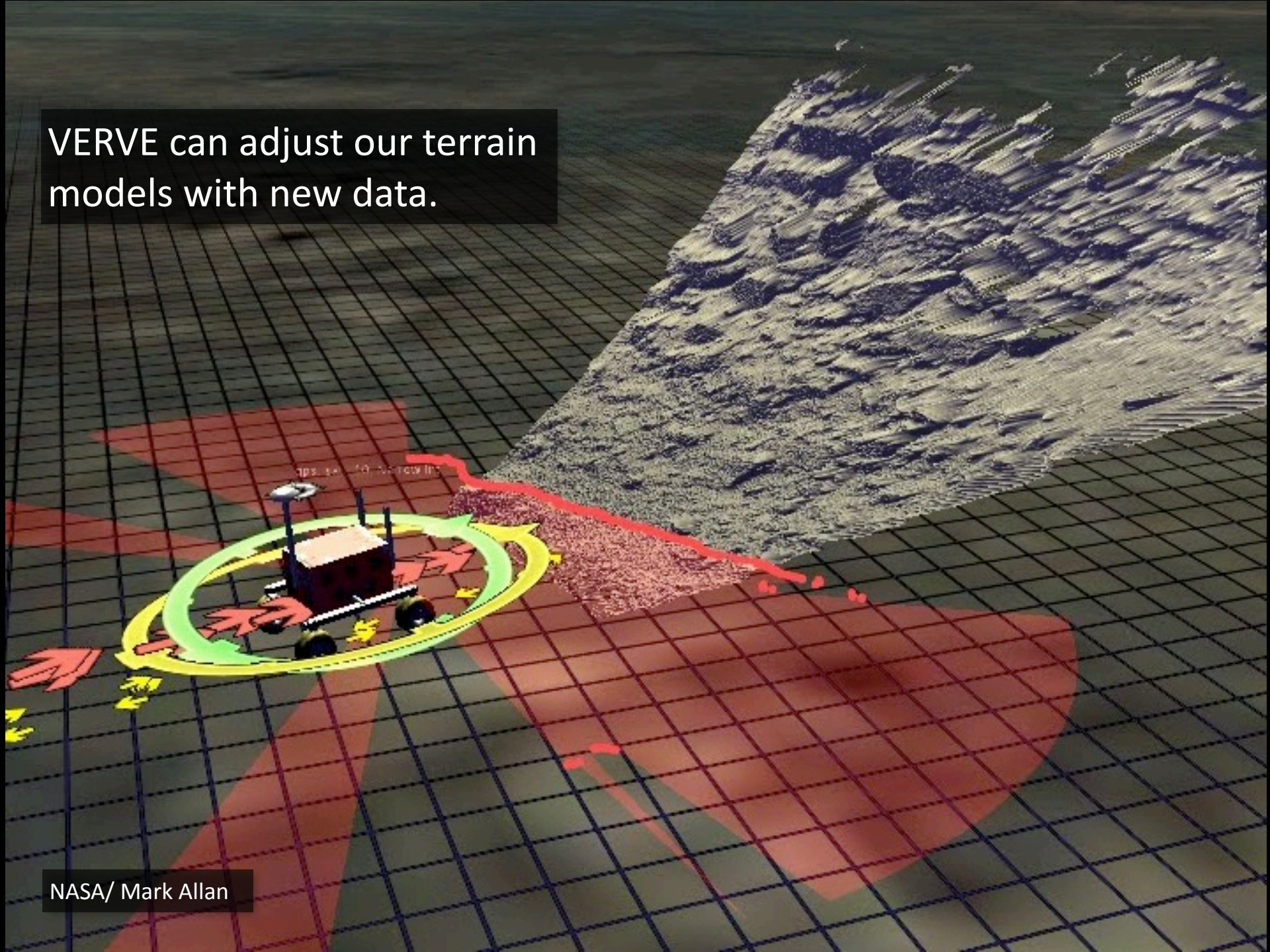


VERVE shows 3D terrain with overlays for rover operators.



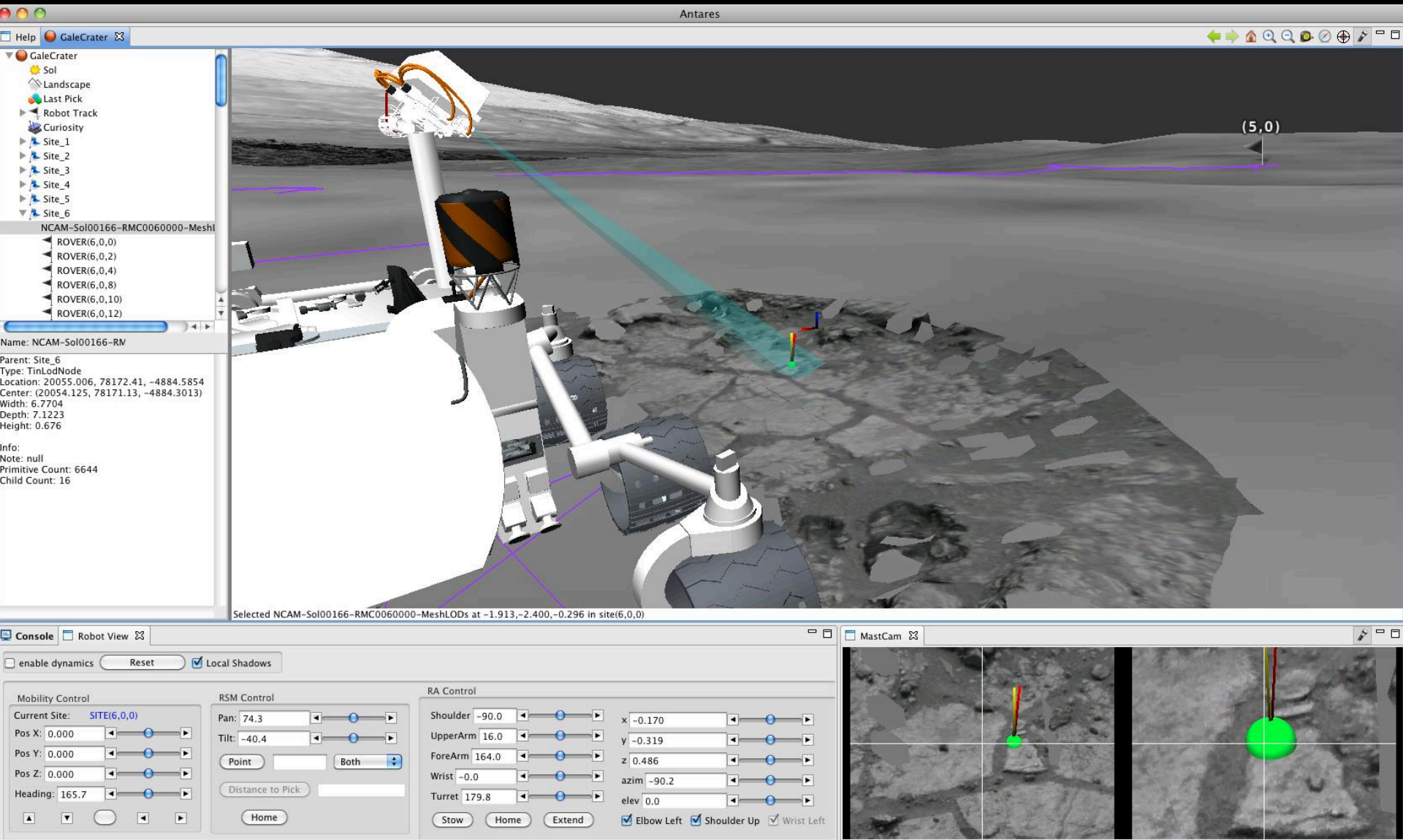


VERVE can adjust our terrain models with new data.



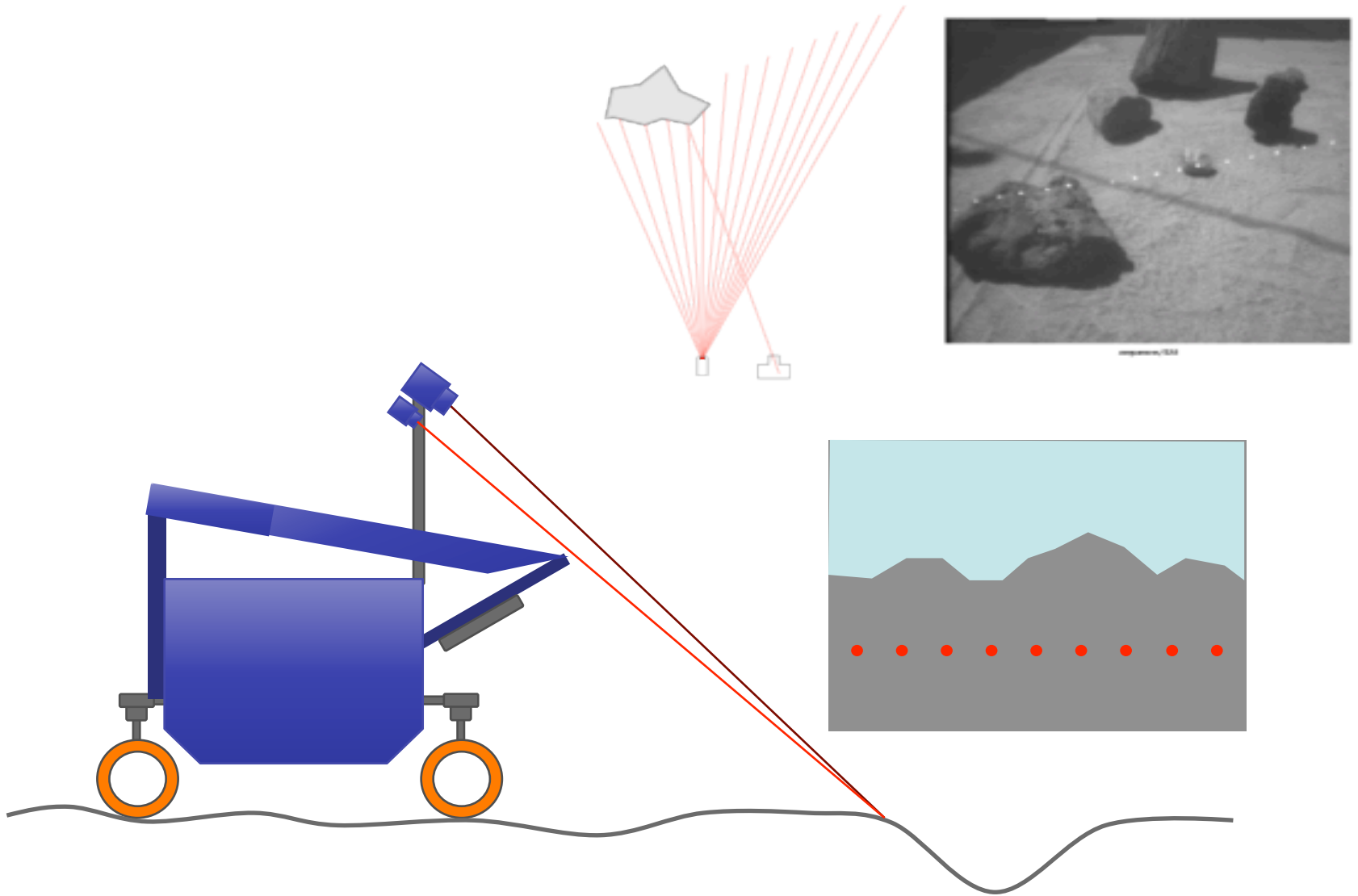


# 2011 Mars Science Laboratory (MSL) & Antares for Curiosity

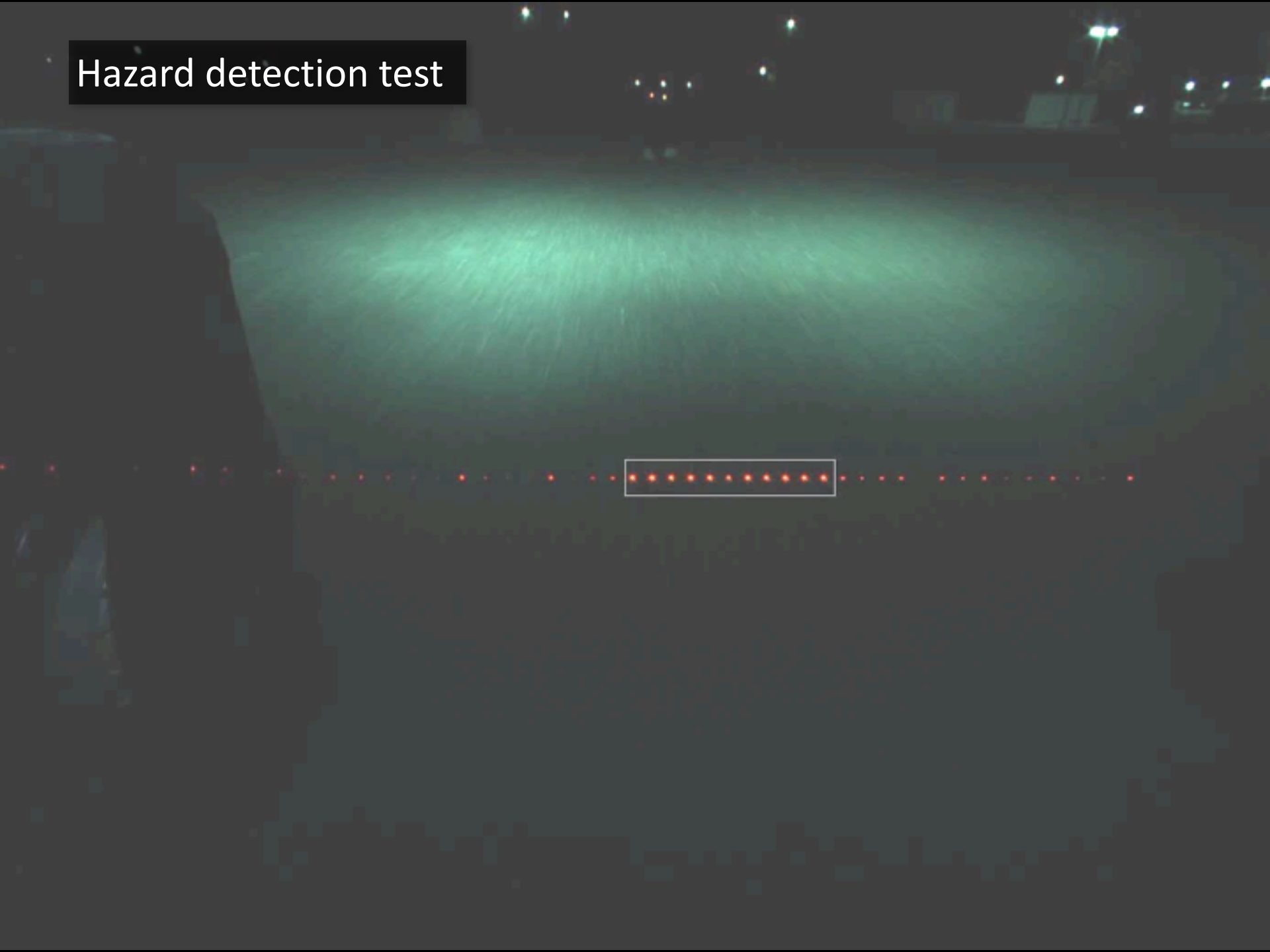


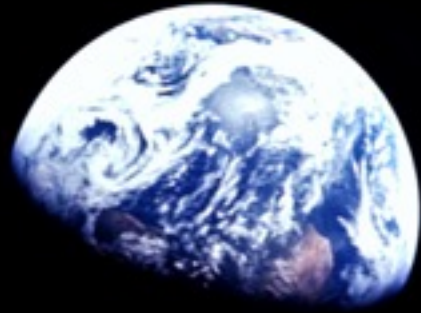


# Hazard Detection with lasers



# Hazard detection test





How do we prepare for a lunar mission?



# We practice at our facilities.



NASA ARC Mission Control  
driving RP15 rover at  
NASA JSC, August 2015



NASA JSC Rock Yard  
from the rover (left)  
stereo camera



NASA KSC Payload Control



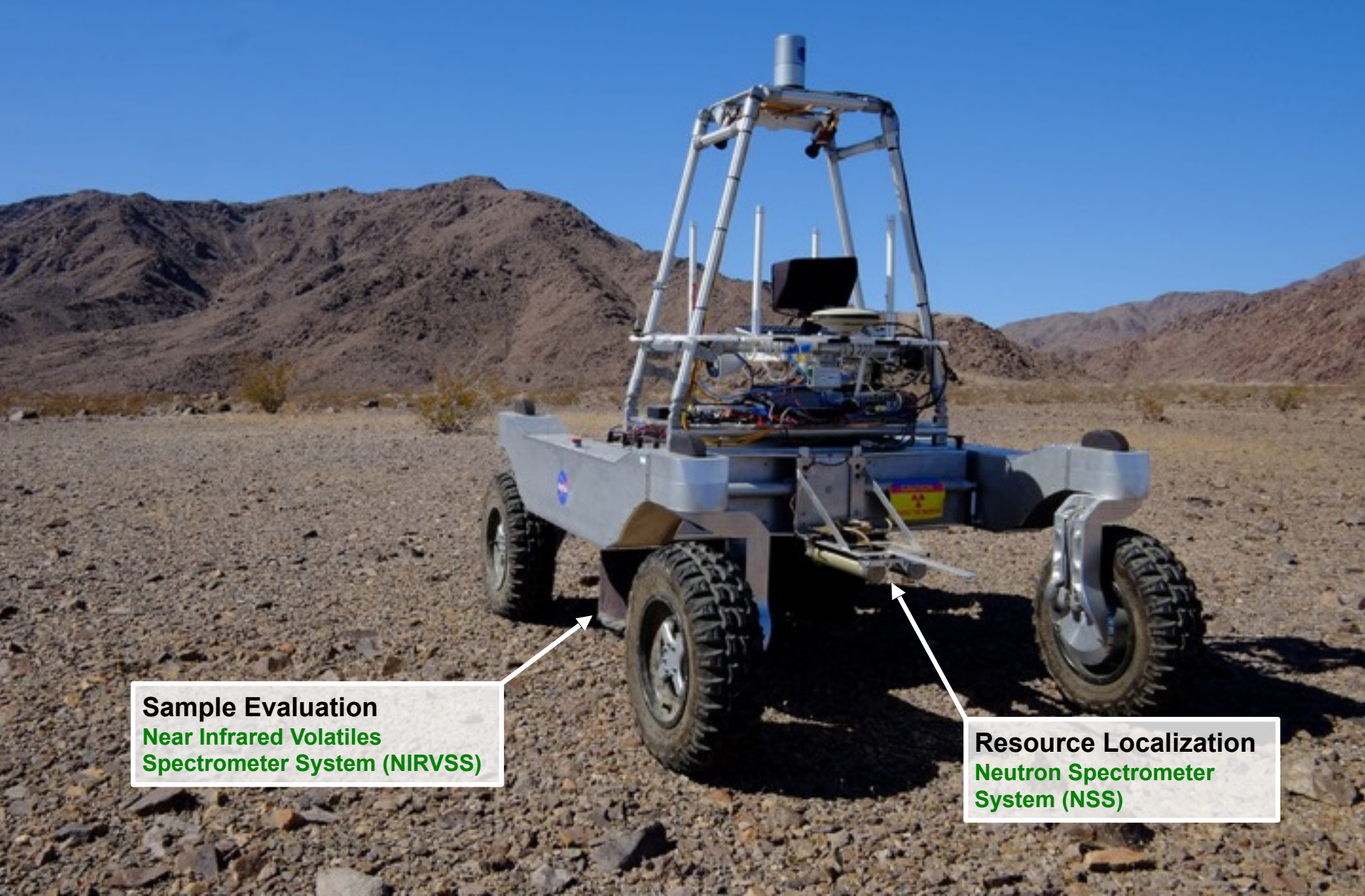
We practice in the field with “Analog Missions”



Mojave Volatile Prospector (MVP) 2014  
K2 rover with RESOLVE instruments



# Prospecting Payload on K-REX Rover



**Sample Evaluation**  
Near Infrared Volatiles  
Spectrometer System (NIRVSS)

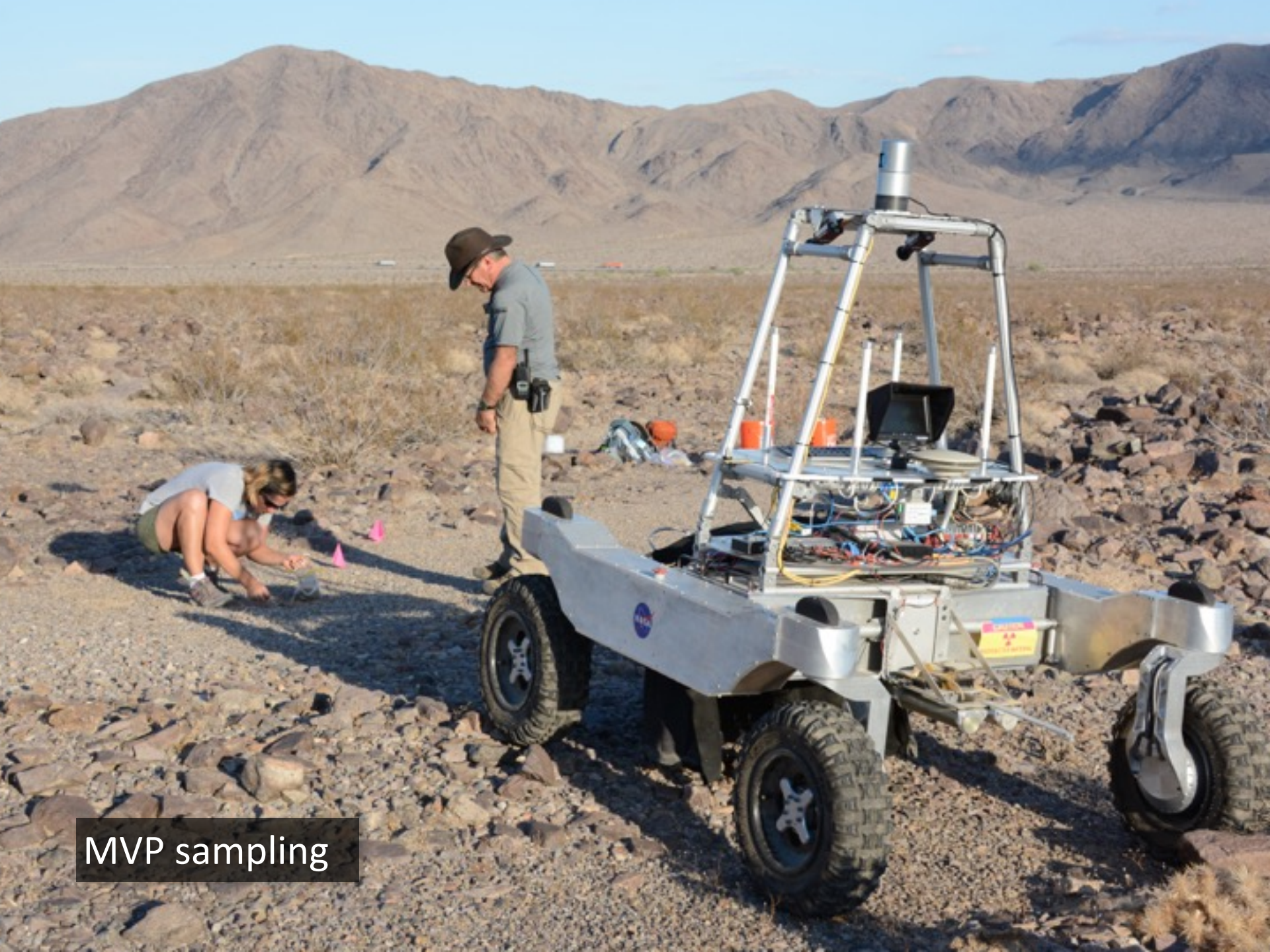
**Resource Localization**  
Neutron Spectrometer  
System (NSS)





Making sure we will find water





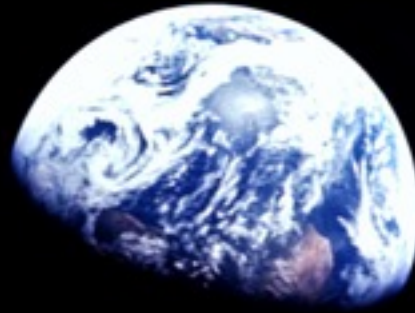
MVP sampling



# Mojave Volatiles Prospector







How do scientists work with the rover?

The science team for MVP works in the back room at NASA Ames



# Exploration Ground Data Systems (xGDS) for rapid remote science



Label	Note	Still	Video
sponge	area of barrel sponges		Full Video Compressed Video
sponge	space sponges		Full Video Compressed Video
other	completed first pass		Full Video Compressed Video
other	going in reverse		Full Video Compressed Video
other	start moving to waypoint		Full Video Compressed Video

Plan

Monitor & Archive

Explore

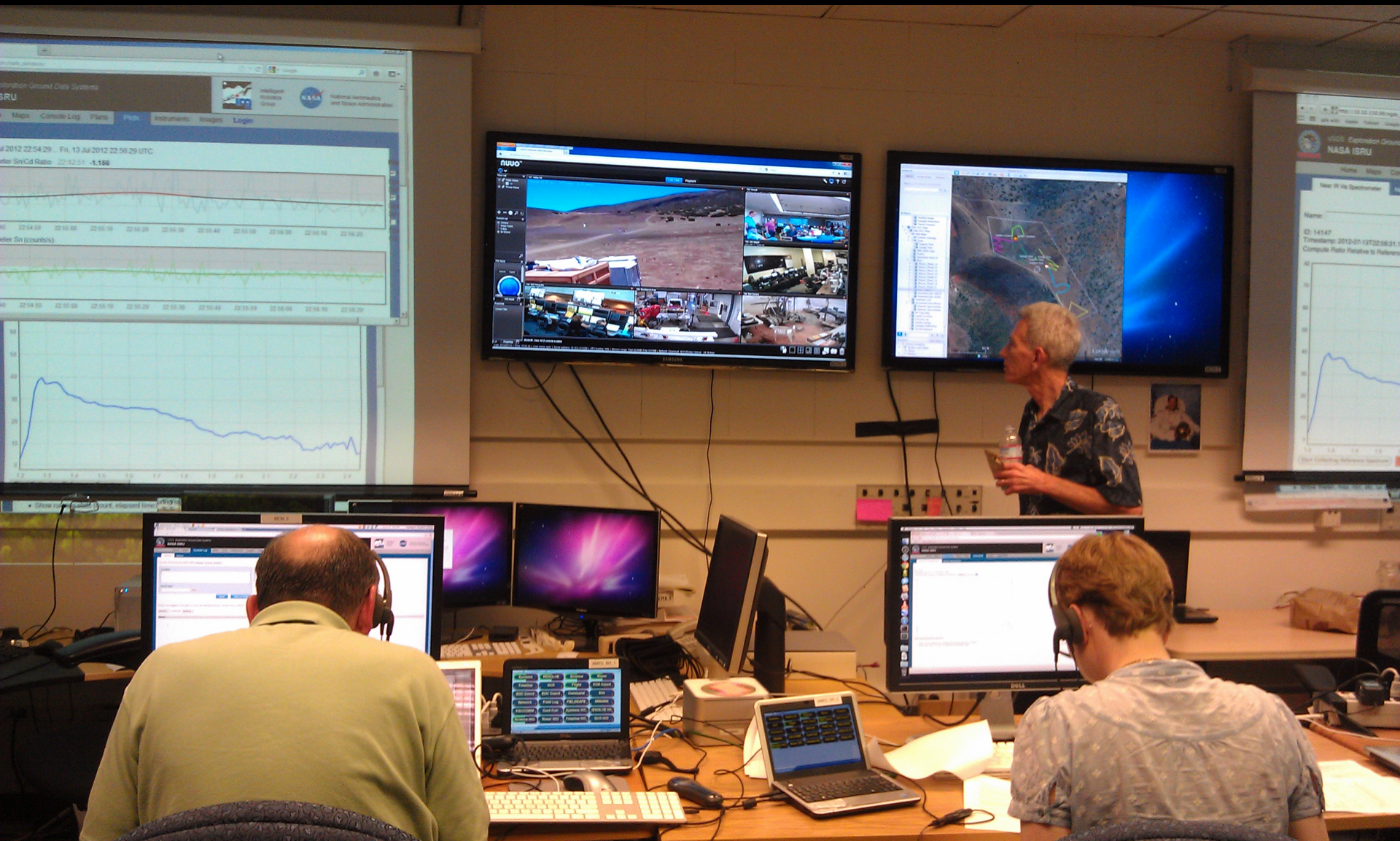
Pre-Mission

During Mission

Post-Mission



Scientists can customize their own views of the data.





Each person in the back room has a particular job.





Scientists must also monitor the rover.





# Scientists take geolocated notes within xGDS



David Lees 10/21/15 17:20:46 HST

Edit Info

Add Note

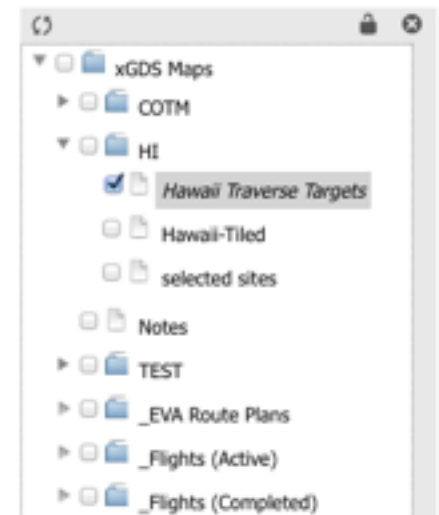
## Notes

Shannon takes a pXRF reading

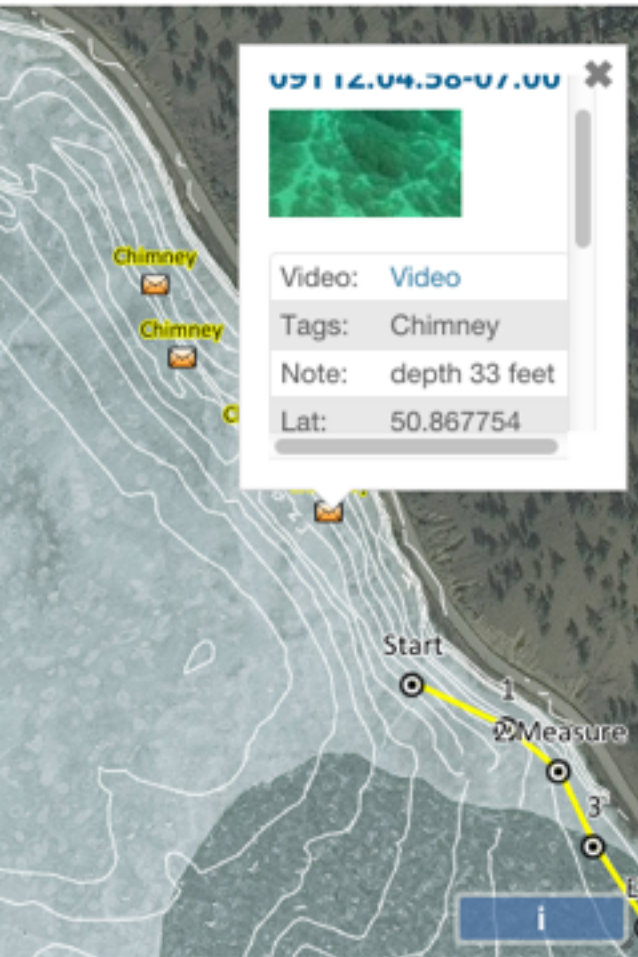
geology x

Save

Sites Ames



# Scientists can search for data within xGDS and use it for planning



Meta Sequence Layers Search Tools Links

Search for:

author

content

flight

label

Depth  up to

New Depth  up to

Display

Search:

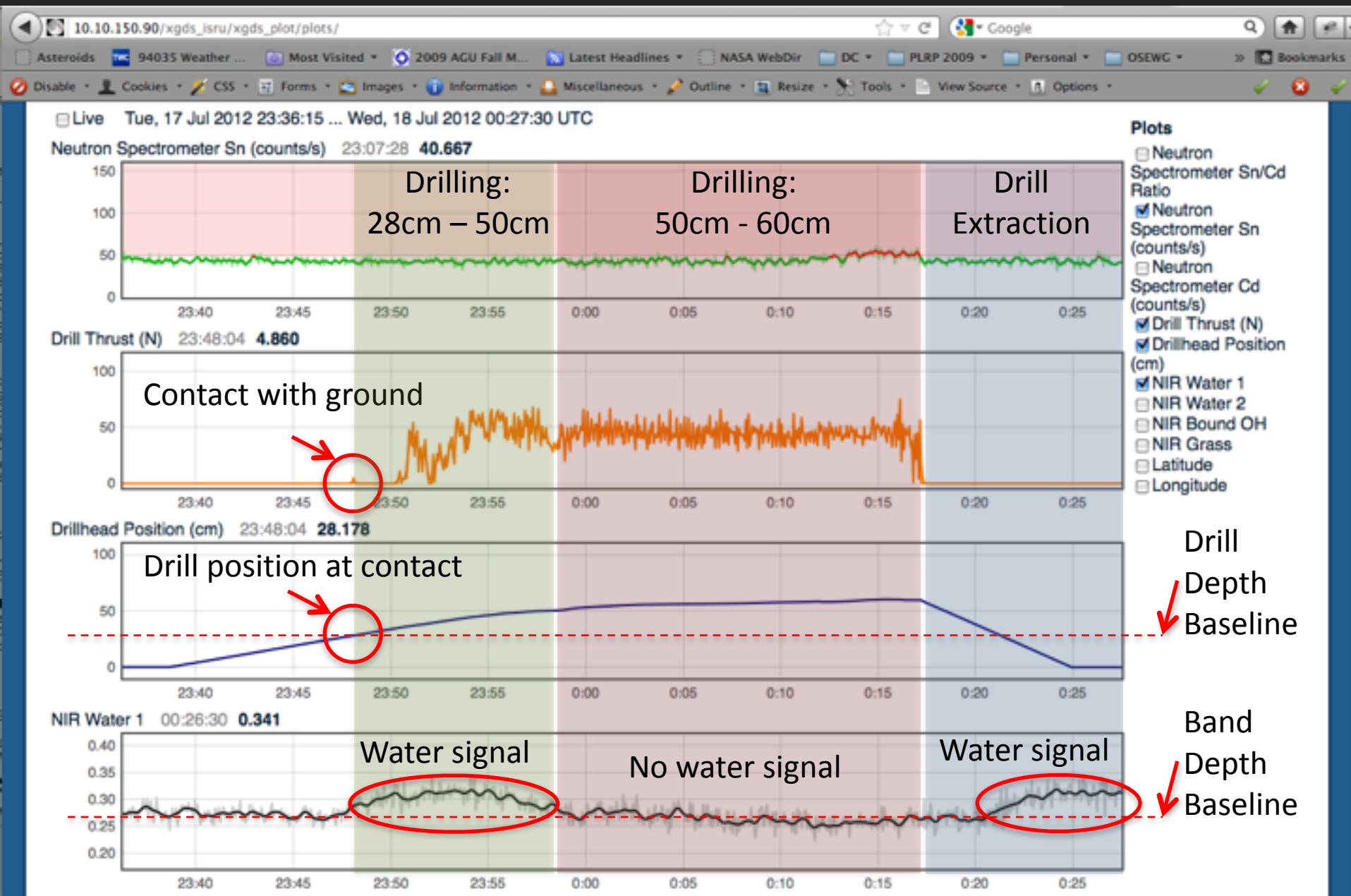
flight	event_time	author	tags	content
	06116:24:54-07:00	Cohen		artichoke like.
20090706B	2009-07-06T15:43:27-07:00	Lisa Leoni	Chimney	observed chimneys, recording, checked nnovia says not recording
20090708C	2009-07-08T17:13:59-07:00	Lisa Leoni	Chimney	tall skinny chimneys.



Scientists can monitor rover position, tracks, notes and other events in xGDS.

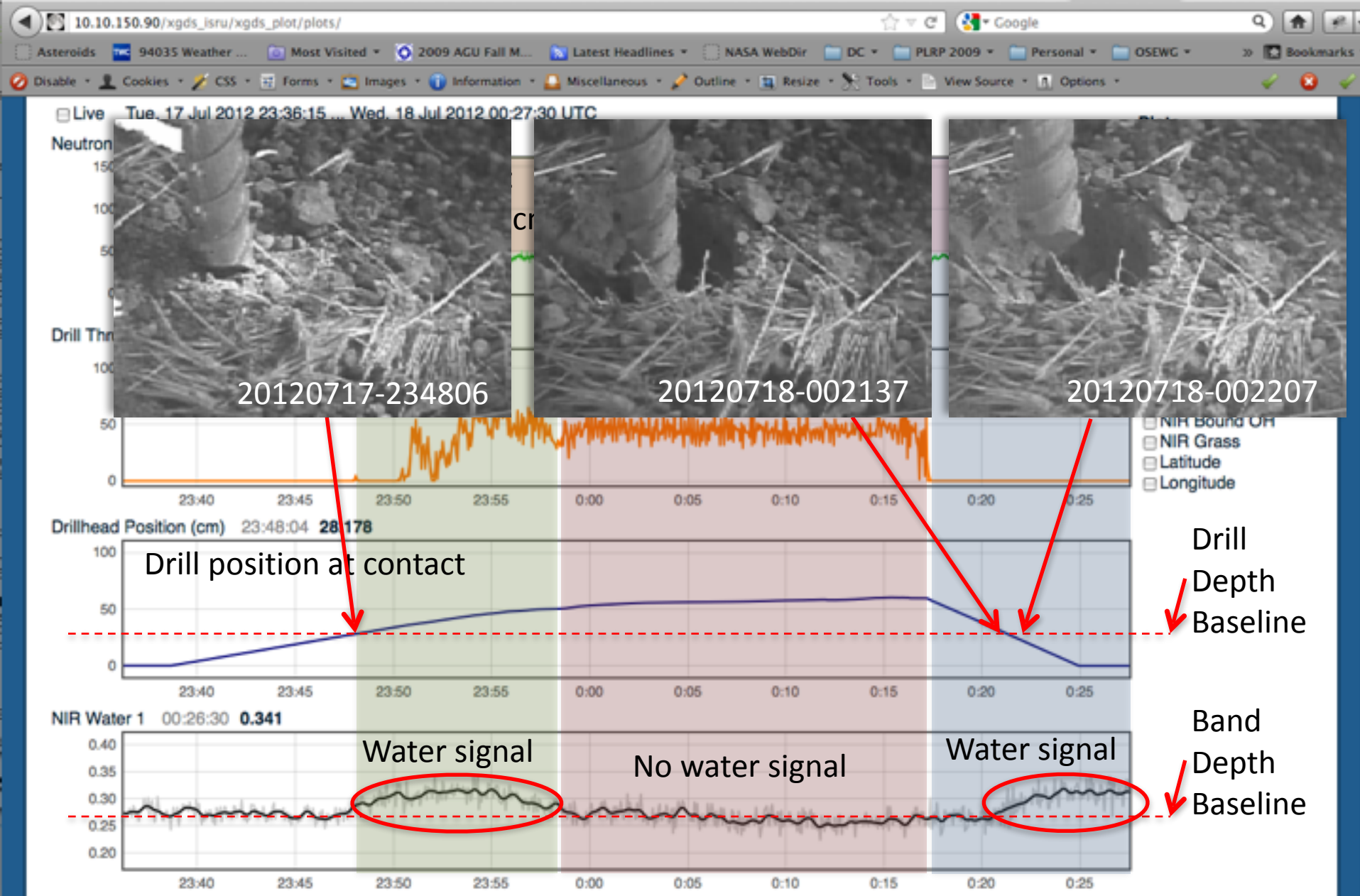


# xGDS aggregates plot data





# Plots correlated with images



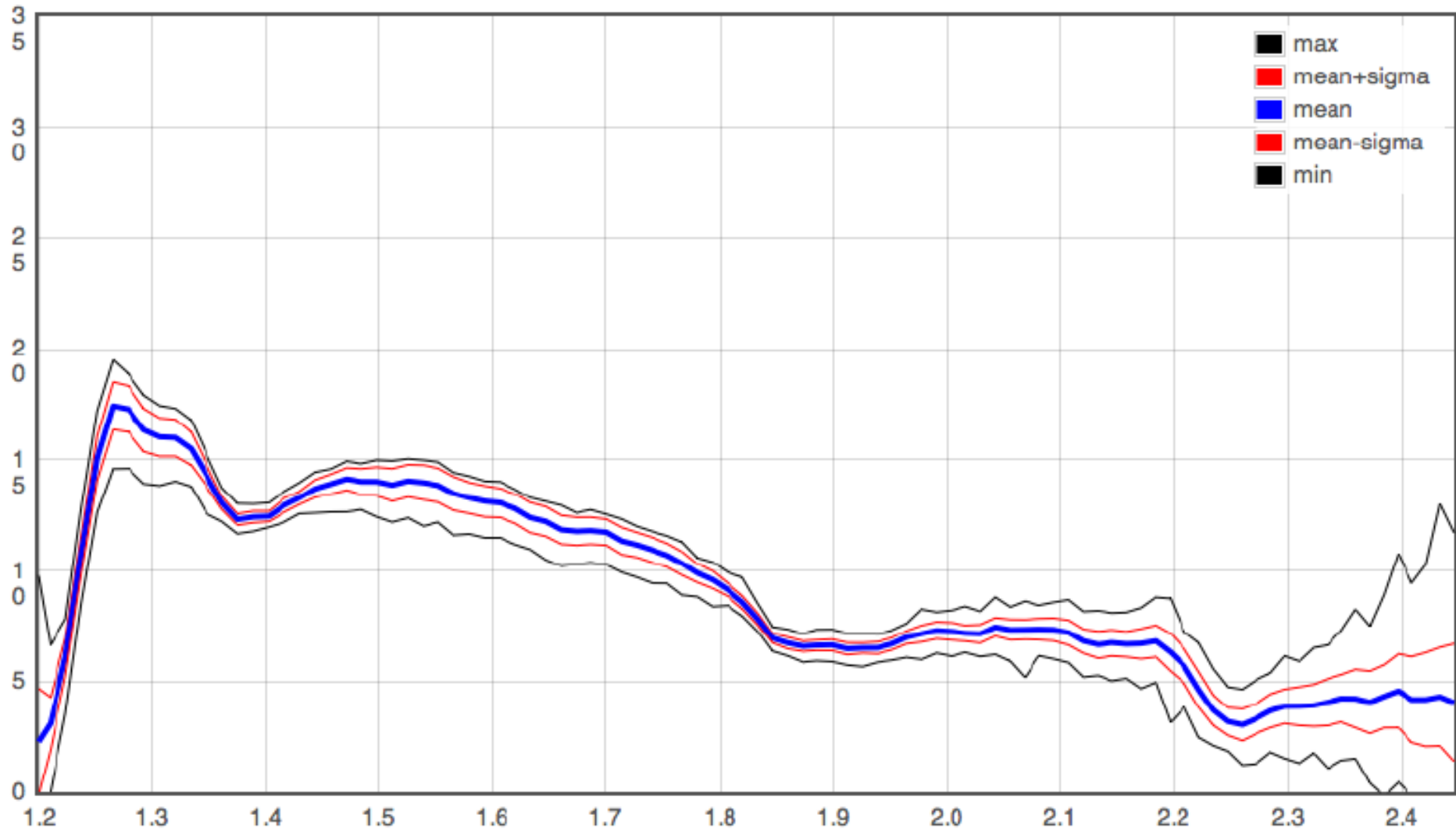
# xGDS can compare instrument readings with reference spectra

Name: 20120714T220410-1sthold-ref

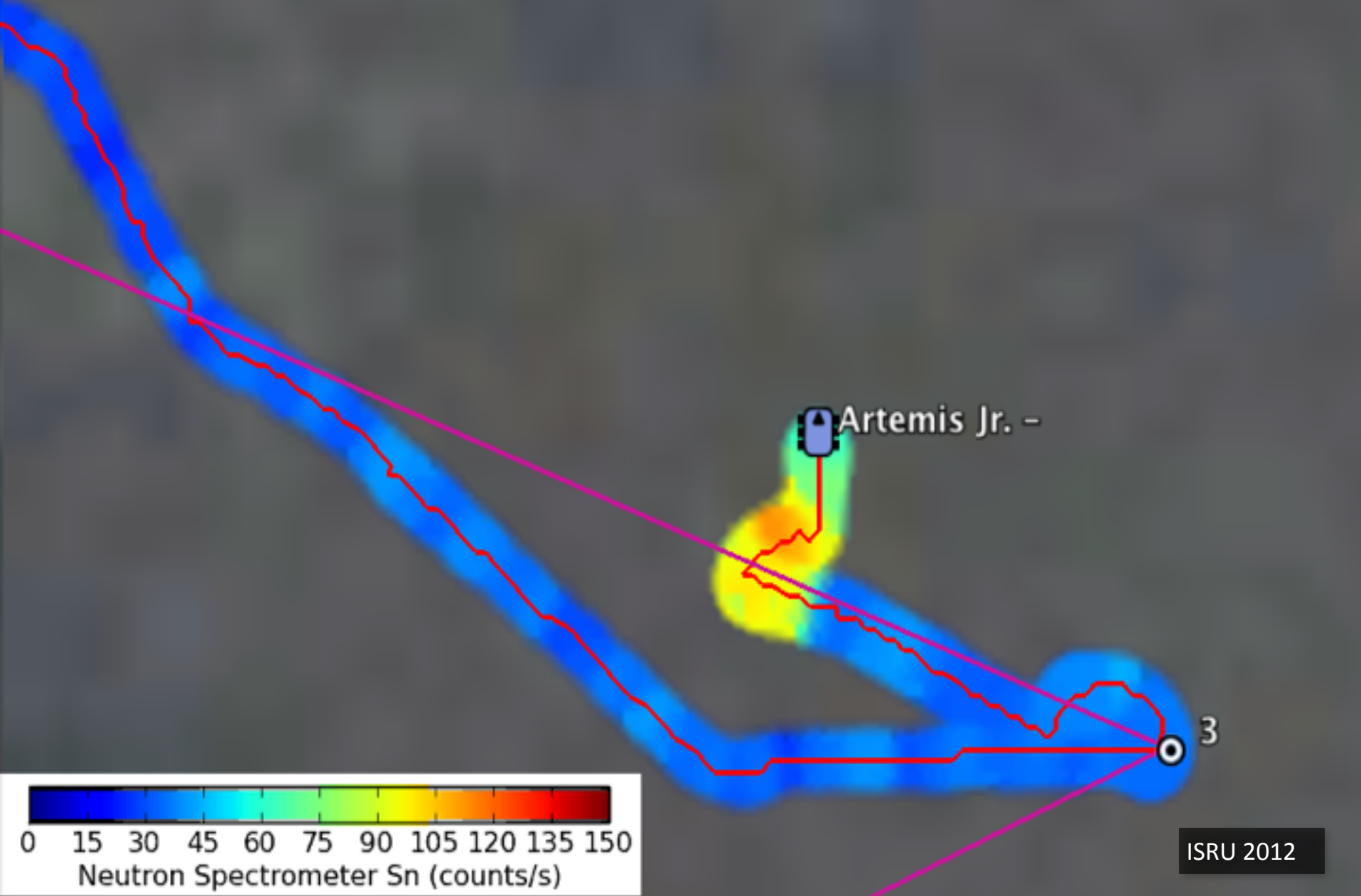
Start Time: 2012/07/14 22:02:43 UTC

Instrument: NSP\_ETU

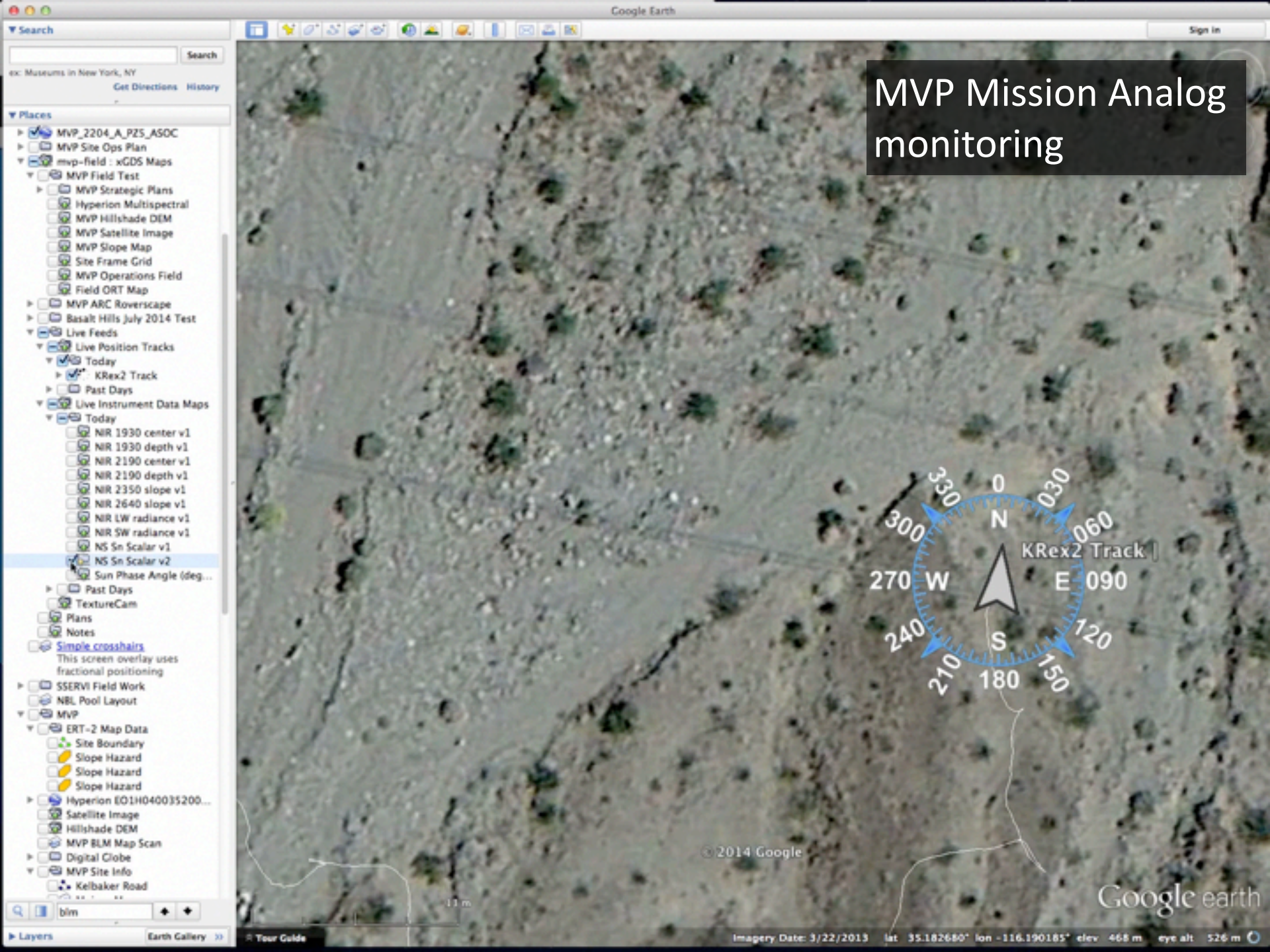
End Time: 2012/07/14 22:04:10 UTC



# xGDS can aggregate instrument readings into heat maps







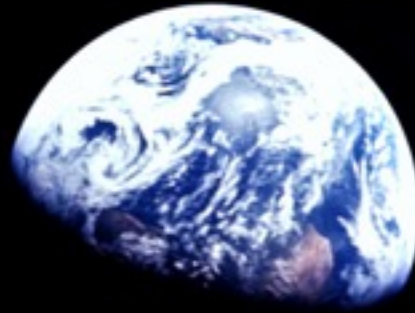
# MVP Mission Analog monitoring

- Search
- Search
- ex: Museums in New York, NY
- Get Directions History
- Places
- MVP\_2204\_A\_PZ5\_ASOC
  - MVP Site Ops Plan
  - mvp-field : xGDS Maps
    - MVP Field Test
      - MVP Strategic Plans
      - Hyperion Multispectral
      - MVP Hillshade DEM
      - MVP Satellite Image
      - MVP Slope Map
      - Site Frame Grid
      - MVP Operations Field
      - Field ORT Map
    - MVP ARC Roverscape
    - Basalt Hills July 2014 Test
    - Live Feeds
      - Live Position Tracks
        - Today
          - KReX2 Track
        - Past Days
      - Live Instrument Data Maps
        - Today
          - NIR 1930 center v1
          - NIR 1930 depth v1
          - NIR 2190 center v1
          - NIR 2190 depth v1
          - NIR 2350 slope v1
          - NIR 2640 slope v1
          - NIR LW radiance v1
          - NIR SW radiance v1
          - NS Sn Scalar v1
          - NS Sn Scalar v2**
          - Sun Phase Angle (deg...
        - Past Days
      - TextureCam
      - Plans
      - Notes
      - Simple crosshairs
        - This screen overlay uses fractional positioning
    - SSERV Field Work
    - NBL Pool Layout
    - MVP
      - ERT-2 Map Data
        - Site Boundary
        - Slope Hazard
        - Slope Hazard
        - Slope Hazard
      - Hyperion EO1H040035200...
      - Satellite Image
      - Hillshade DEM
      - MVP BLM Map Scan
      - Digital Globe
      - MVP Site Info
      - Kelbaker Road
- Layers
- Earth Gallery
- Tour Guide

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Google earth

Imagery Date: 3/22/2013 lat 35.182680° lon -116.190185° elev 468 m eye alt 526 m



What will this mission accomplish?



We will have expanded  
human knowledge about  
the moon.





NASA builds our tools on open source software.

When you contribute to open source software, you may be helping NASA explore our universe.



A word cloud of open source software libraries and frameworks used by NASA. The words are arranged in a roughly triangular shape, with 'Python' at the top. The colors of the text vary, including orange, blue, red, yellow, green, and purple. The words are: Python, Flot, MariaDB, Cesium, Eclipse, Bower, Gridstack, GDAL, OpenSeadragon, OpenLayers, Backbone, Java, Proj4js, JQuery, and Django.

Python  
Flot MariaDB  
Cesium Eclipse  
Bower Gridstack GDAL  
OpenSeadragon  
OpenLayers  
Backbone Java  
Proj4js JQuery  
Django

NASA releases open source software.

[software.nasa.gov](https://software.nasa.gov)

[code.nasa.gov](https://code.nasa.gov)

[github.com/nasa](https://github.com/nasa)

[ti.arc.nasa.gov/opensource/projects/](https://ti.arc.nasa.gov/opensource/projects/)



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